Certus

Scanning Probe Microscope

User manual

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This user guide is intended for installation and operation of a Scanning Probe Microscope Certus. Scanning Probe Microscope is a combination of XYZ scanner, cantilever tip sensor (deflectometer), SPM controller EG-3000 and software NSpec. Scanning Probe Microscope Certus is used in NST devices: Certus Standard, Certus Optic, Certus NSOM (model based on Certus Standard and Certus Optic), Centaur (HR) and is used as a standalone tool for objects positioning.

Before installation and operation this appliance, please read the manual. On all matters related to technical support and upgrades for this product, under the additional features, contact the following addresses:

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Read this first!

Laser radiation.

When you work in certain modes, using a scanning probe microscope Certus, laser light sources of varying power and wavelength are used. Before working with SPM Certus, we encourage you to read the documentation for the specified source of laser radiation and safety for the class of the laser source. In the case of an external laser in the recording system of the microscope or with a combination of SPM Certus with external laser sources, we recommend that you study the documentation and safety for your laser source.

Precautions.

SPM Certus - this is a complex research tool. Strong physical impacts, operation in hostile environments, changes in the structure during use, storage or transportation can result to device damage.

Modification and user self-alignment of SPM Certus with research equipment.

In the case of user self-alignment of **SPM Certus** with research equipment, or modification to the specific research tasks recommended to agree the matter with the company "Nano Scan Technology", because the user self-interference in the construction without the agreement deprives the guarantee.

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Introduction

This user guide describes SPM Certus, specifically designed to work with optical equipment, such as optical microscopes, spectrometers and other similar devices. SPM Certus is the basis of such devices and systems, as Certus Optic, Certus NSOM, Certus Standard, Centaur and Centaur HR. Universal SPM controller EG-3000 and software NSpec is need for SPM Certus operation.

1. Basic Information about SPM Certus

1.1. SPM Certus application

Certus - specialized scanning probe microscope (SPM), specially designed to work with optical equipment for combining the techniques of scanning probe microscopy and optical microscopy and spectroscopy. XYZ scanning head with piezoceramic stacks is a base of the system.

SPM Certus is designed for imaging and studying the surface properties of various substances, materials and structures, both natural and artificial. For example, the study of surface properties of polymer, biological, inorganic, and semiconductor materials, biological cells, tissues, individual biological structures and biomolecules, covered, electronic equipment, etc.

SPM Certus possible applications:

- Topography imaging;
- Surface roughness determination;
- Surface spectroscopy;
- Nano lithography;
- To obtain relevant information about the physical and chemical properties of the sample surface;
- When combined with optical methods to receive and collate information about the spectral and topographic (depending on the technique) the surface properties of objects under investigation.

General list of tasks implemented by the SPM Certus, determined by the used method.

1.2. Specification

1.2.1. Data Sheet

	Main data sheet	
1	**SPM scanning head**	
1.1	Built-in XYZ scanner (flat stage)	
1.1.1	Range	100x100x15 µm
1.1.2	XY resonant frequency	1 kHz
1.1.3	Z resonant frequency	7 kHz
1.1.4	Lateral (XY) resolution	<1 nm
1.1.5	Vertical Z resolution	<0.1 nm
1.1.6	Residual non-linearity	<0.3%
1.1.7	Minimum step	0.1 nm
1.2	Displacement sensors	
1.2.1	Sensors type	Capacitance
1.2.2	Operation principle	TDC (time to digital convertors)
1.3	Scanner material	Aluminum alloy

1.2.2. Sample size

min	any
max with system holder	Up to Ø 125 mm and 16 mm height.
max without system holder	any

1.2.3. Deflectometer lasers

Default	650 nm, <1 mW, Class II
IR	1300 nm, <1 mW, Class II

1.2.4. SPM head Certus Drawings

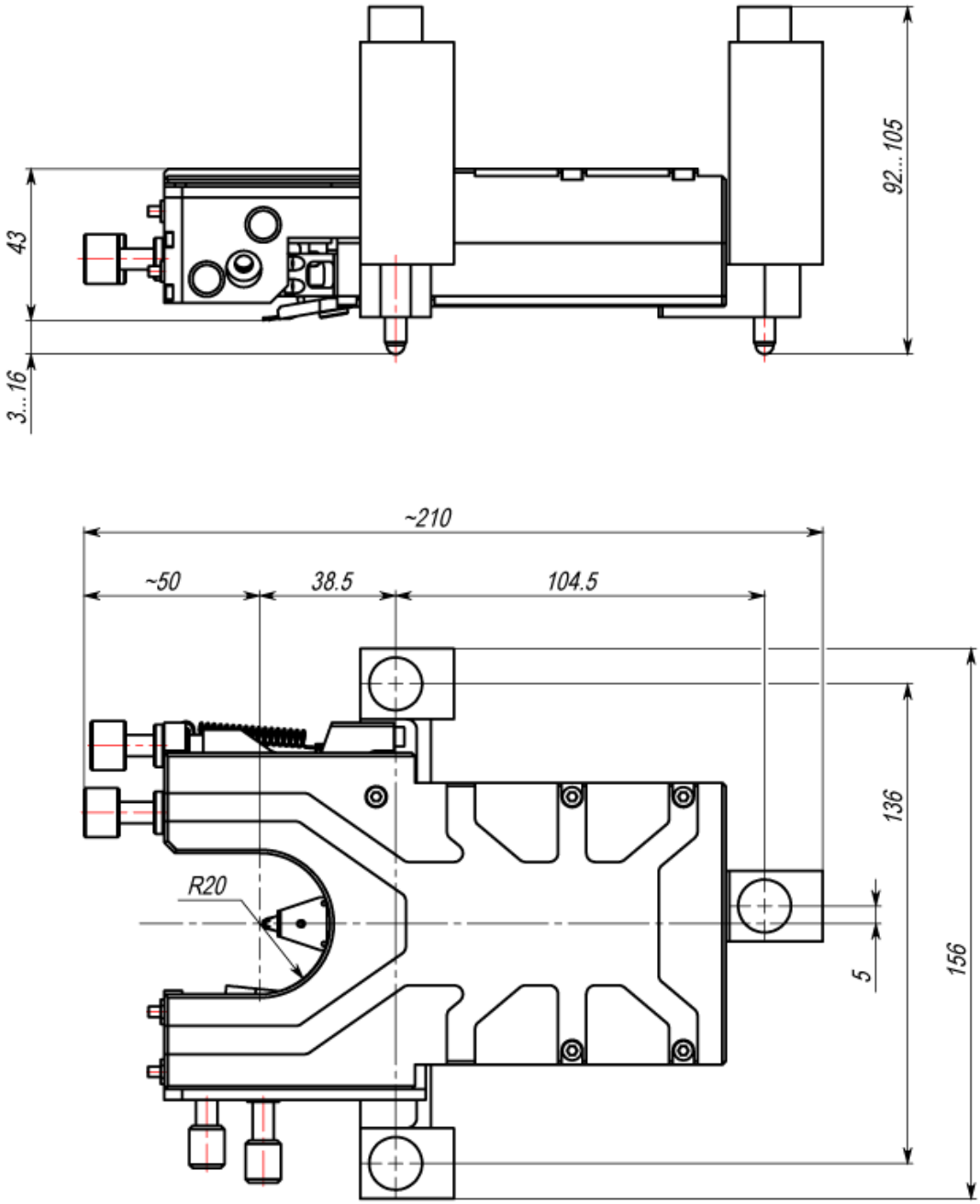


Fig. 1.1 SPM Certus drawings.

1.3. Operating conditions

SPM Certus is a complex, high-precision research instrument. To ensure normal operation of the device are advised to observe the following conditions of use and storage:

1	Temperature	
1.1	Range	10÷50°C
1.2	Optimum	22±3°C
*When delivered, SPM Certus scanner adjusted to the optimum operating temperature. When the room temperature is different from the optimum, but within the permissible operating temperature range, necessary to calibrate the scanner at current temperature in the room.		
2	Humidity	
2.1	Maximum	80 %
2.2	Optimum	65±15 %
3	Atmospheric pressure, mm. Hg	760±30
4	Power requirements	
4.1	Voltage, V	220 (+10%/-15%)
4.2	Frequency, Hz	50/60
4.3	Ground	required
5	Noise and vibration	
5.1	Vibration sensitivity range, Hz	1÷100
5.2	Maximum vibration magnitude in range	0.5 μm
5.3	Maximum sound pressure within 10000 Hz	35 dB
6	Shield from :	
6.1	Direct sun light	required
6.2	Heating	required
6.3	Electromagnetic radiation	required
6.4	Air/gas flow	required
7	Extra recommendation	
7.1	Frequent and abrupt changes in temperature and humidity, affect to performance and the quality of the results.	
7.2	Running compressors, traction control, laminar boxes, cooling devices, and similar sources of periodic or random noise can create background noise.	
7.3	Recommended to place Ratis with maximum possible distance from the computers, monitors and peripheral devices.	
7.4	Avoid strong mechanical influences on Ratis, as this may lead to failure of the mechanics and control electronics unit.	

1.4. Safety regulations

1	Safety regulation	
1.1	Ground	Recommended to check equipment ground
1.2	Opened parts	Work is prohibited, with the removed cover and the casing.
1.3	Cables connect/disconnect	Cables connecting/disconnecting to device connectors can be done while device is off.
1.4	mount/dismount device units	Only specialists of «Nano Scan Technology», certified specialists, in consultation with «Nano Scan Technology»
1.5	External equipment connection	Only in agreement with the company «Nano Scan Technology»
1.6	Liquid	Not accepted.
2	Laser radiation sources	
2.1	Deflectometer laser	In accordance with the class of security established by the laser safety class and characteristics of the laser described in the SPM head under the label shown in Fig. 1.2.
2.2	External lasers	In accordance with the marking on external sources of laser radiation

Fig. 1.2 The warning label on the laser source.

1.5. Terms of storage and transportation

1.5.1. Storage

The device should be stored in compressed form in a special room with no abrupt changes in temperature and humidity.

1	Temperature	22±10°C
2	Humidity	Maximum 80%

1.5.2. Transportation

When transporting, instrument should be packed in the original package or in any other package, which excludes the damage.

After transport at temperatures below 0°C, before starting the device, wait 3 hours.

1.6. Description of basic units

SPM Certus includes:

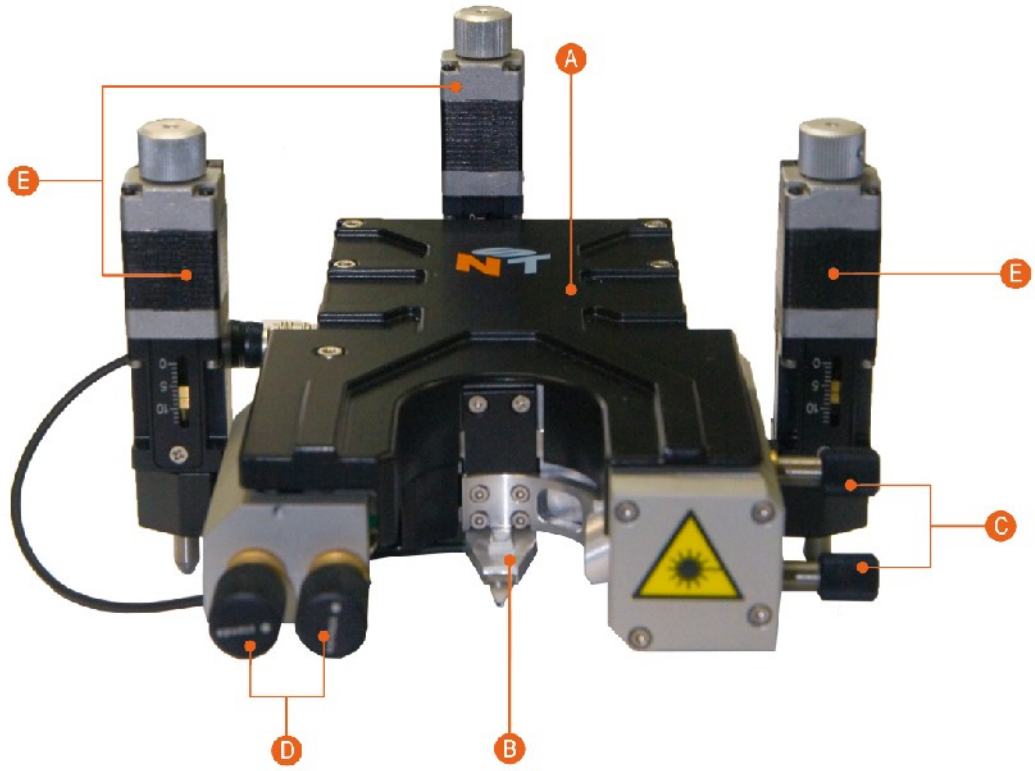
- Certus scanning head;
- EG-3000 Controller;
- NSpec software.

1.6.1. Scanning Certus head

The basis of scanning probe microscope Certus is a scanning head of a new generation. The main distinguishing features of SPM Certus are:

- Built-in XYZ flat scanner (scanning stage) with capacitive displacement sensors;
- Modular architecture, allows to use different lasers for deflectometer, including external laser sources;
- easily removable probe holder, which allows the use of fundamentally different types of probes;
- open work area (the contact point of the probe and the sample), which provides easy monitoring of the probe, the input of external radiation, etc.;
- parallel to the probe to sample approach system with the ability to automatically align the head over the plane of the sample;
- Full digital connection between the head and controller.

Plane scanner (stage) is a monolithic metallic body (made of quality Al alloy), in which with EDM and other methods of precision machining, formed channels for piezoelectric actuators (piezoelectric stacks), mobile elements of the scanner, etc. This design provides excellent linearity and flatness of travel, in contrast to piezoelectric tubes, a scan surface which is a sphere. In addition, the plane-scanners have high mechanical stability compared to the brittle piezoelectric-tubes.



A	Certus head body with built in XYZ flat scanner (stage).
B	Probe holder.
C	Screws for laser beam to cantilever bulk alignment.
D	Screws for reflected laser beam to PSD diode alignment.
E	High precision actuators for approach system.

Fig. 1.3 SPM Certus head.

Certus head scanner is equipped with capacitive displacement sensors. The measuring method is based on TDC (time-to-digital converters), that are physically located as close as possible to the sensors, that give digital signal proportional to measured capacitance. This method enables high-precision measurements and transmission current sensors position to the controller, with long cables without sacrificing the quality of measurements.

In the standard configuration deflectometer diode laser with a wavelength of 650 nm is used. At the request of the customer may use another, for example infrared, laser. In addition, fiber optic port can be installed for connecting an external laser. The head comes with several detachable probe holder: standard cantilevers, probes such as tuning fork with a vertical or horizontal. At the request of customers can be developed mount virtually any original probes.

Unique "open design" SPM Certus enables high multiples of the external lenses, illuminators, condensers microscopes, etc. to illuminate the work area, monitor the

sample and the probe, to take stock of the radiation to the point of contact tip and sample. For Certus head control, universal controller EG-3000 and software NSpec are using.

1.6.2. EG-3000 Controller

EG-3060/3060A controller designed to control the operation of scanning probe optical or confocal microscope. The controller collects data from various sensors and external devices and provides control outputs to the piezoelectric positioning devices, in addition, all the gathered information is to be sent to the control computer for subsequent processing and visualization. Also, computer controls all parameters of movement and scanning. Exterior view of the controller is shown in Fig. 1.4:

Fig. 1.4 EG-3000 SPM controller.

For the control of positioning devices system uses a digital feedback and the original scheme for measuring capacitance displacement sensors, based on the TDC (time to digital converter). Capacitance measurement is carried out in the scanning device and controller receives a digital signal. Such a system increase accuracy and significantly improve the device immunity.

Any of the signals available in the system can be used to operate the feedback of the tip-sample distance. The controller keeps the feedback on the six channels simultaneously, which allows to scan by tip or by sample.

In order to implement the modulation technique microscopy (such as, for example, non-contact atomic force microscopy), controller provides dual-channel lock-in amplifier, equipped with a highly stable master oscillator which is made on the basis of the digital frequency synthesizer. High-speed digital data processing implemented using programmable logic (FPGA), allows synchronous detection of signals at frequencies up to 1.5 MHz.

Controller provides stepper motors control, allowing to connect from 4 to 12 drives in a micro stepping mode.

The device has additional analog inputs and outputs for connecting external devices, as well as inputs and outputs for synchronization with external equipment. USB interface is used for communication with the host computer. The controller is managed by the specialized software NSpec and EG3000 Dll.

EG-3000 detailed information is described in the manual: "SPM controller (model EG-3060 and EG-3060A).

1.6.3. NSpec Software

NSpec software is used to control devices:

- Certus Light (including SPM head Certus);
- Certus Standard (including the SPM head Certus);
- Certus Optic (including SPM head Certus);
- Certus NSOM (including SPM head Certus);
- Centaur (including SPM head Certus);
- Centaur HR (including SPM head Certus);
- Snotra;
- Ratis.

The program is based on multythread kernel, written in C++ and built by compiler GCC4. The program interface is built using cross-platform libraries and libraries QT4, QWT. The program is compatible with all current versions of OS Windows (XP, 2003, Vista, 7). Upon request, the program can be transferred to the operating system Linux, * BSD, MacOS. Only basic functions of data processing are implemented to NSpec software, and tools for optimal adjustment of scanning parameters. Specialized software is recommended to use for full data processing, such as Gwyddion. For processing the spectral data is also recommended to use specialized programs such as GRAMS. To facilitate the transfer of data to other applications NSpec program supplied by the filters of import/ export formats ASCII, gwy (Gwyddion), spc (GRAMS).

1.6.4. Systems and devices, which includes Certus SPM head

- **Certus Light** – minimum configuration, includes **Certus head**, simple basement with sample holder, controller and software.
- **Certus Standard** – normal SPM configuration, includes **Certus head**, basement with sample holder and translator, video microscope, controller and software.
- **Certus Optic** – Extended SPM configuration, integration with inverted or

upright high resolution microscope, includes **Certus head**, scanning basement with XY (XYZ) scanning stage, 6 (9) channel controller and software.

- **Certus NSOM** – Near Field Optical Microscope, SPM Certus head adaptation for near field microscopy.
- Centaur – includes **Certus head** in SPM part of the system, Raman system, combining the techniques of scanning probe microscopy, Raman/fluorescence confocal microscopy/spectroscopy, conventional optical microscopy.
- Centaur HR – includes **Certus head** in SPM part of the system, Raman system, combining the techniques of scanning probe microscopy, Raman / fluorescence confocal microscopy/spectroscopy, conventional optical microscopy, and spectrometer with high resolution.

2. Operating principles

2.1. SPM common principles

Scanning Probe Microscope — device for surface imaging and local properties information.

In basic case Scanning Probe Microscope (fig. 2.1) includes:

- Probe;
- XYZ scanning/positioning system;
- Probe sensor for determination interaction with surface.

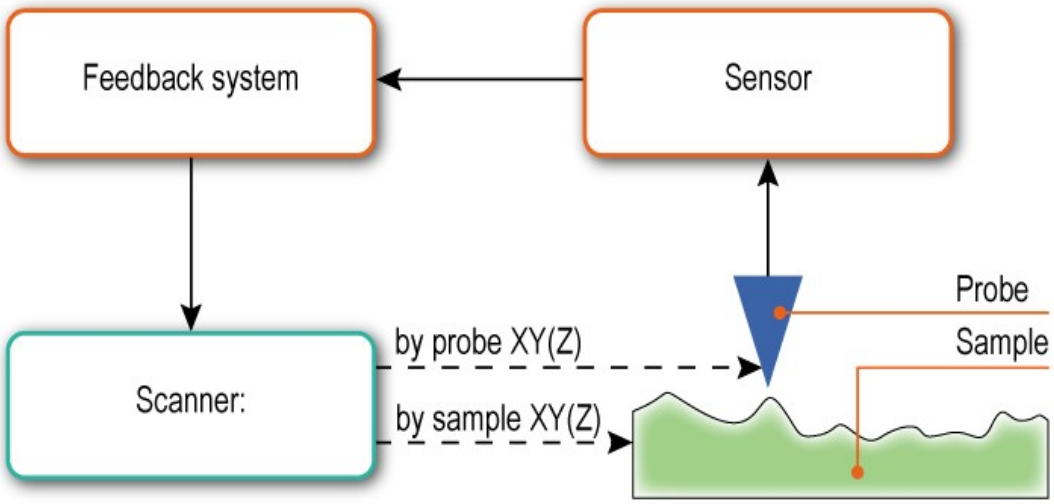


Fig. 2.1 SPM basic system.

The operation of scanning probe microscope based on the principle of obtaining information about the interaction of the probe to the surface at one point. At a small distance between the surface and the probe, one can fix the forces of interaction (repulsion, attraction, and other forces) and the appearance of different effects (for example, tunneling of electrons). These interactions and effects can be detected with modern means of registration. To register, use different types of sensors, whose sensitivity allows you to record such disturbances.

To construct a bitmap image uses a system of probe movement (scanning system) relative to the surface in XY or XYZ coordinates.

The recording system records the value of each item. Basicly, the recorded value, depending on the magnitude of the interaction between the probe and the sample sur-

face. On the basis of known or suspected plots of the interaction of the distance between the probe and surface during scanning constructed surface topography (3-D image co-ordinates XYZ). In that case, if the registration of change of the interaction from a distance does not make sense or it can not be determined uniquely, then constructed the distribution of the measured parameter on the surface (3-D image, where XY is based distribution parameter, and the Z value of a parameter) (Fig. 2.2).

The system of negative feedback controls the position of the sample or the probe by one of the coordinates (in most cases, Z). As a system of feedback is most commonly used PID controller.

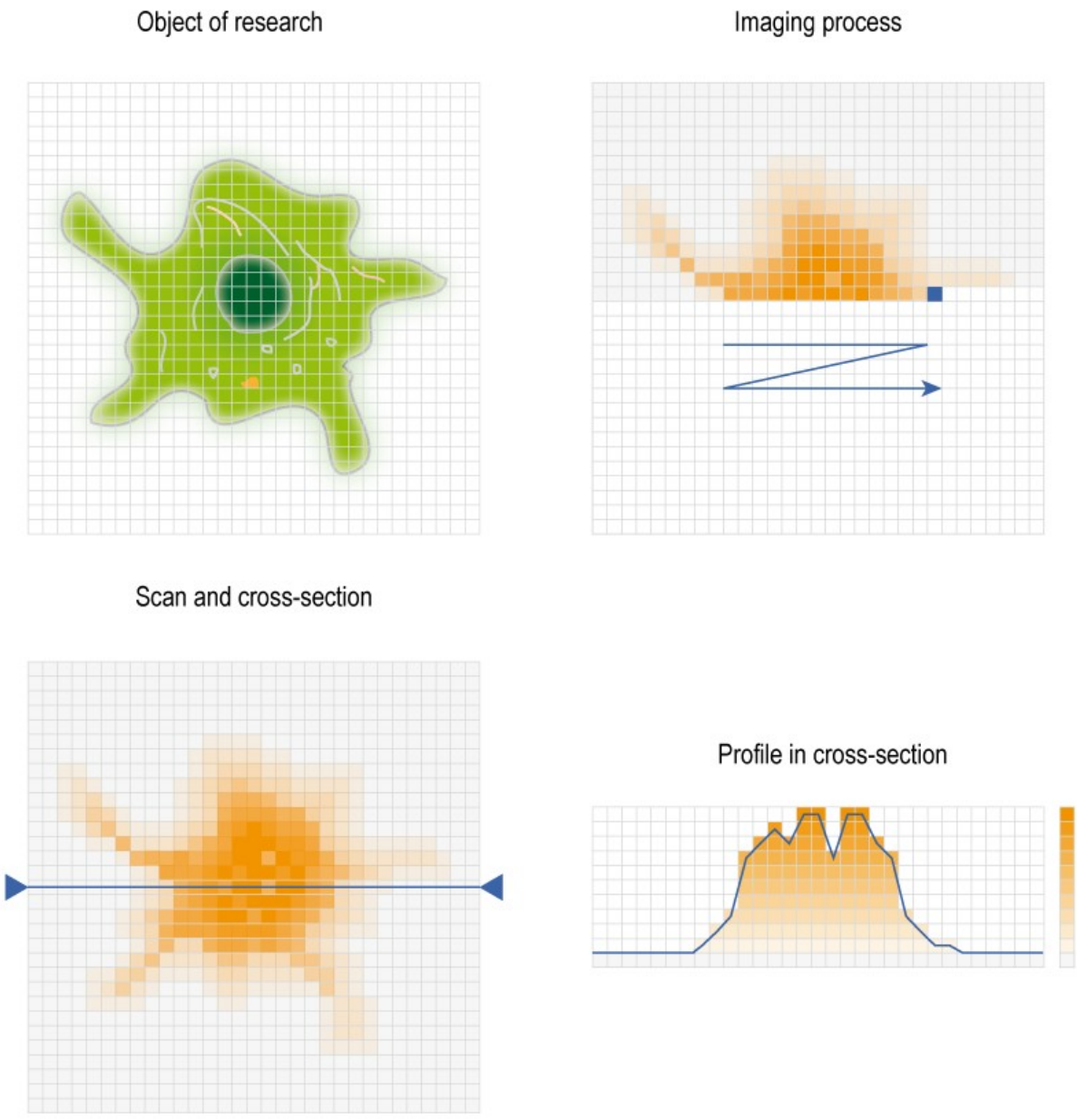


Fig. 2.2 Common principles of SPM surface imaging.

The main difference between scanning probe microscopy techniques is in selected for the registration parameters and methods of registration.

2.2. Probe scanning/positioning

XY (XYZ) scanning process is used to get the image in scanning probe microscopes.

2.2.1. Scanning

The scanning process proceeds as follows. The scanner performs a raster movement of the object (Fig 2.3). System takes signal measurement and digitizes data at nodes of the raster to receive information about the surface characteristics. The direction of lines along which scanner moves, is called the fast scan direction. Perpendicular direction is called slow scan direction.

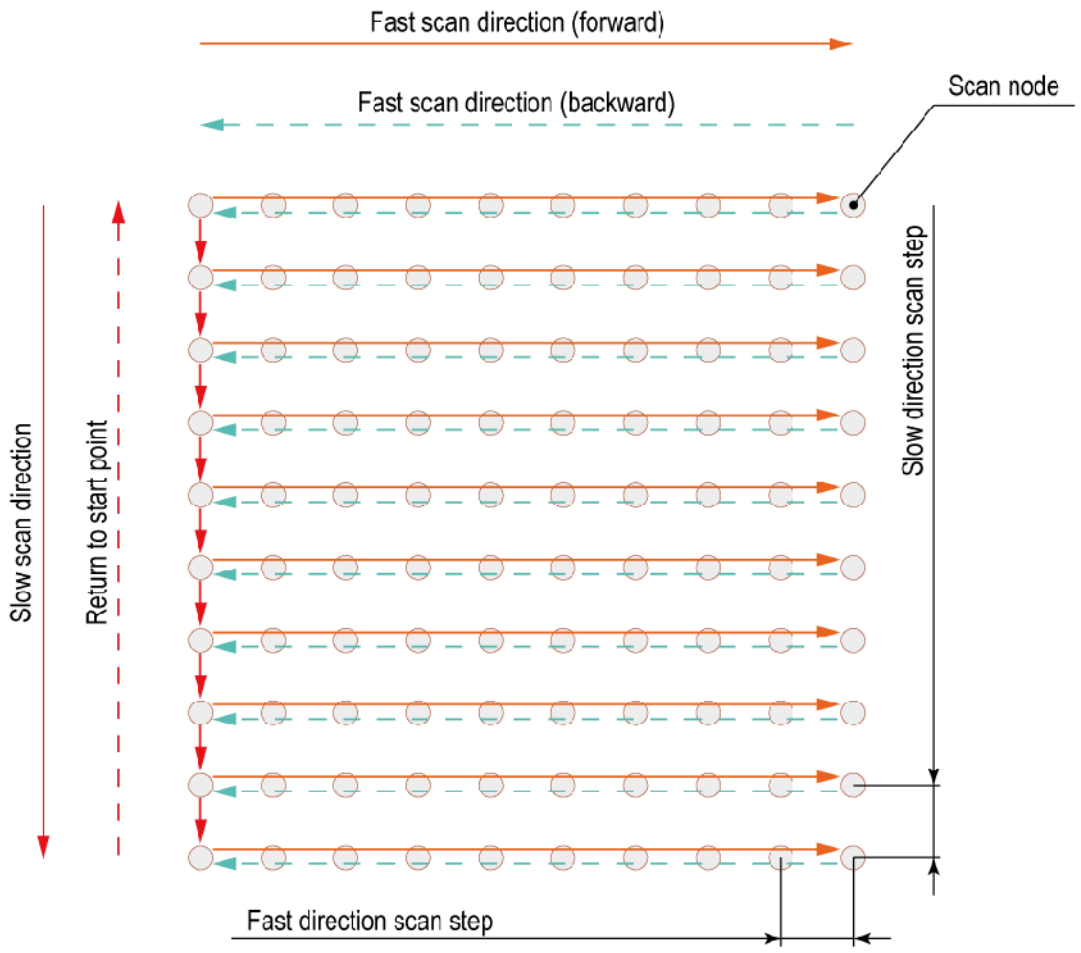


Fig. 2.3 Scanning process illustration

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One can write data on direct, and on reverse the course of scanning, producing a shift in the perpendicular direction. In this case, the speed of image acquisition doubles. However, for scanners without sensors such scanning method is not applicable, since for scanning probe microscopes there is difference between the surface profile at the forward and reverse course because of the nonlinear properties of piezoelectric ceramics, and this is usually essential. Scanners with sensors also have a distinction between "direct" and "reverse" profile, although not always visible. This cause of the error feedback in the direction of fast scanning. These errors are reduced with decreasing scanning speed. As a result, it often turns out that to obtain the desired image quality is advantageous to use record data only on the direct or only on reverse course.

2.2.2. Piezoelectric phenomena

All modern scanning probe microscopes, scanning/positioning systems, regardless of design, for positioning and movement uses the inverse piezoelectric effect.

Inverse piezoelectric effect - the effect of mechanical strain in dielectrics under the action of an electric field. It occurs in crystals, which cells have no center of symmetry, resulting to permanent electric dipole in such cells. The application of such a crystal, an external electric field causes deformation of the dipoles, leading to a change in crystal size. Since the growth of single crystals of materials with piezoelectric properties is of considerable difficulty, usually use polycrystalline materials - ceramics, dipoles in the crystals are oriented predominantly in one direction of polarization in a strong magnetic field. Accordingly, they change its size, caused by appearance of electric field (Fig.2.2).

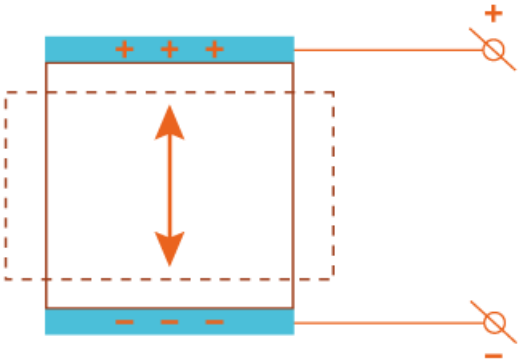


Fig. 2.2 Piezoelectric phenomena.

Piezoelectric properties of the materials described by a set of piezo factors. As a rule, even for a relatively small extension, high voltage should be attached to the material. For example, for lead titanate (PZT, $Pb(Zr_{0,55}Ti_{0,45})O_3$ with additions of Nb, Cr, La, Fe, etc.) piezo factor is

$d_{33} = 374 \times 10^{-12}$ m/V (for PZT-5A).

To reduce the voltage control signal, serial connection of layers of piezoelectric

ceramics with electrodes on each layer are used (Fig. 2.5). In a more advanced version, solid array of piezoelectric ceramics with electrodes in the piezostack body is used.

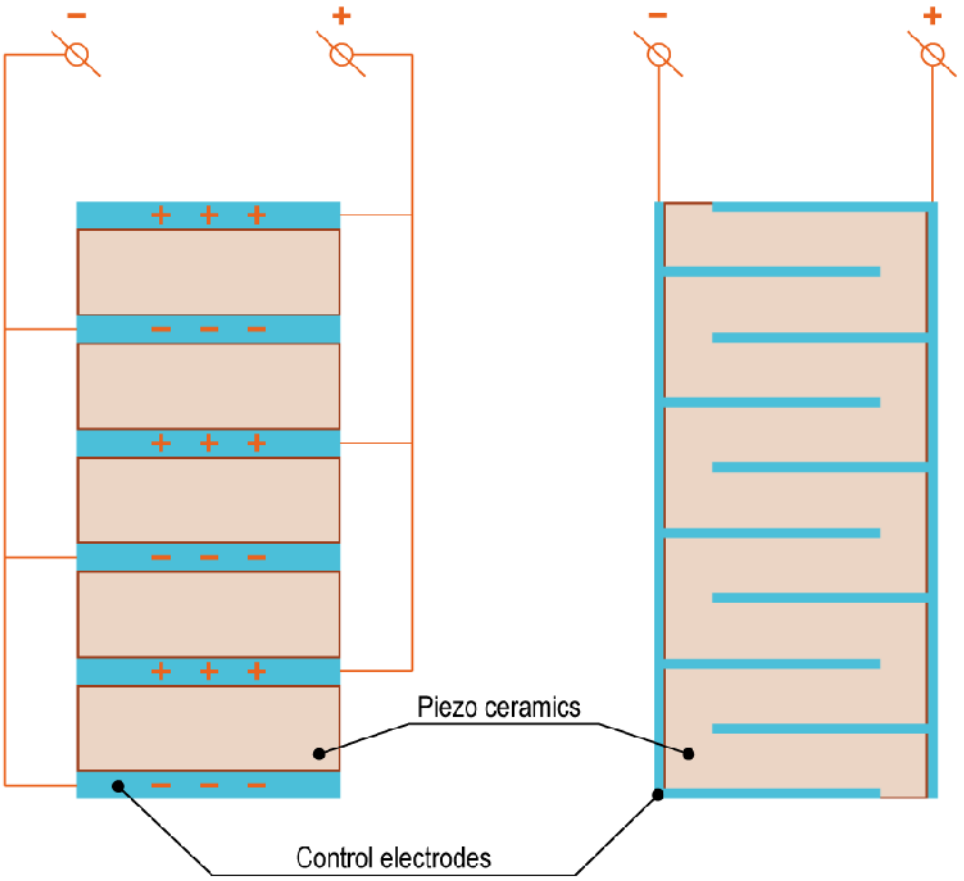
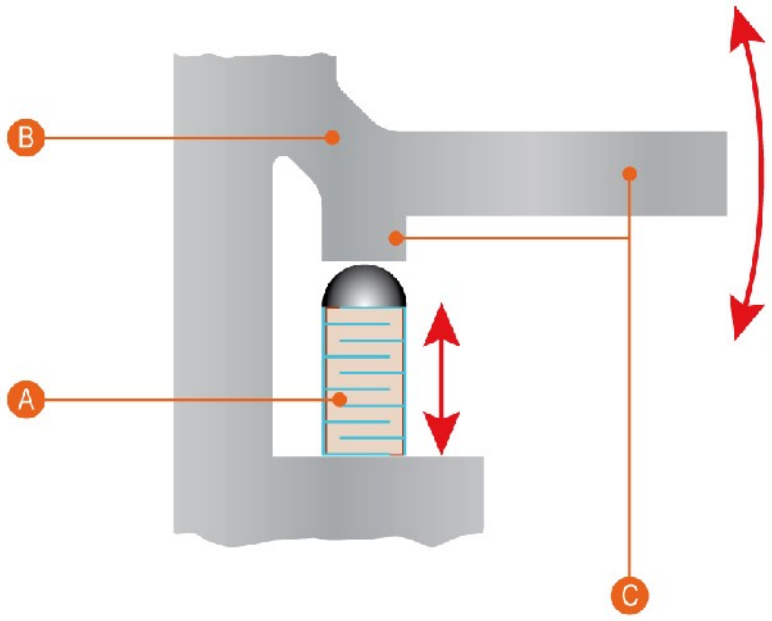


Fig. 2.5 Piezostacks.

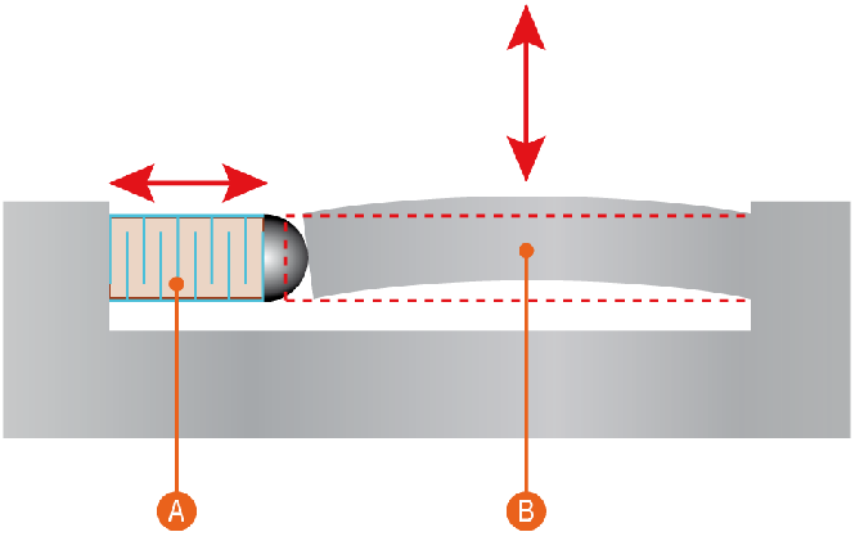
2.2.3. Lever translation systems

In general, the displacement caused by the inverse piezoelectric effect, relative to the size of the piezo ceramic element is a very small amount. The strain usually does not exceed 0.1% of total elongation of the device, displacement value is several tens of micrometers. To increase the displacement, variety of mechanical devices such as levers, hinges (Fig. 2.6), and devices running on a bend (Fig. 2.7) are used.



A	Piezo stack.
B	Elastic Point.
C	Lever.

Fig. 2.6 Lever displacement system diagram.



A	Piezo stack.
B	Bulk.

Fig. 2.7 Bending displacement system diagram

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Typically, the piezoelectric driving element is used only for forward movement, for the return traffic the fact that in the range of applied loads, the materials used are subject to Hooke's law, i.e. the strain is directly proportional to the applied voltage and the material of the device undergoes only elastic deformation. As a result, after the termination of the external force elements of such a system take initial size, shape and, accordingly, the position in space.

2.2.4. Displacement sensors

Because of the nonlinear properties of piezoelectric ceramics, obtained image contains distortions. Because of nonlinear properties of piezoelectric ceramics, it is important to understand features of the dependence between the control electric field and the deformation of the piezo ceramic sample, namely, non-linearity and ambiguity of this relationship. Usually, the nonlinear properties of ceramics are divided into creep, hysteresis and non-linearity itself. Also nonlinear properties includes volatility and sensitivity of the piezo ceramic. Non-linearity and ambiguity of the dependence of the control voltage - the situation often leads to significant distortions of the image.

For the correction of displacement, many types of displacement sensors can be used. It can be optical, inductive, magneto, capacitor, etc.

In the two-dimensional scanning stage Ratis, capacitive sensors are used. The operating principle of such sensors are displayed in Figure 2.9.

Since, the capacity of a flat capacitor consisting of two parallel plates is given by 2.1:

$$C = \varepsilon \varepsilon_0 \frac{S}{d} \quad (2.1)$$

C – capacitance;
S – capacitance plates area ;
d – plate distance ;
ε – dielectric factor;
ε_0 – dielectric constant.

When the distance between the plates changes the sensor capacitance, offset of the axis can be measured.

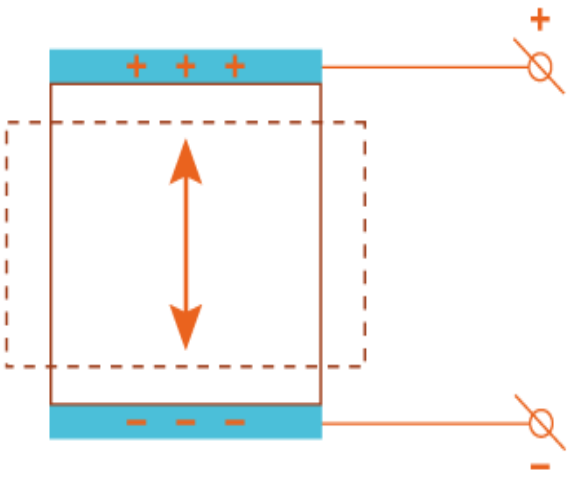


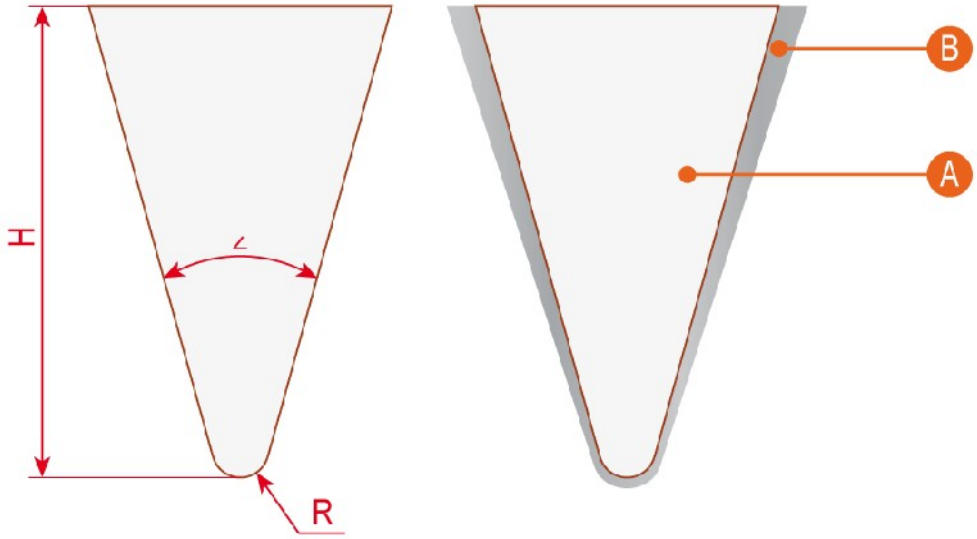
Fig. 2.9 Capacitance sensors diagram.

2.3. Probes

2.3.1. Probes main parameters

The main element of any scanning probe microscope – is the probe. Based on the interaction of the probe with the surface, image of the surface is constructed and the distribution on the surface of local physical characteristics.

In general, a scanning probe microscope is a conical needle or pyramidal shape. The most common material for the probes are metals (tungsten, platinum, and similar to scanning tunneling microscopy), silicon and silicon nitride - Si3N4 for atomic force microscopy, silica coated magnetic and conducting techniques, silicon with a diamond coating for indentation, etc. General view of the probes is shown in Figure 2.9.



A	Probe body.
B	Coating.
R	Tip curvature.
H	Tip Height.
∠	Cone angle.

Fig. 2.9 Probe drawing.

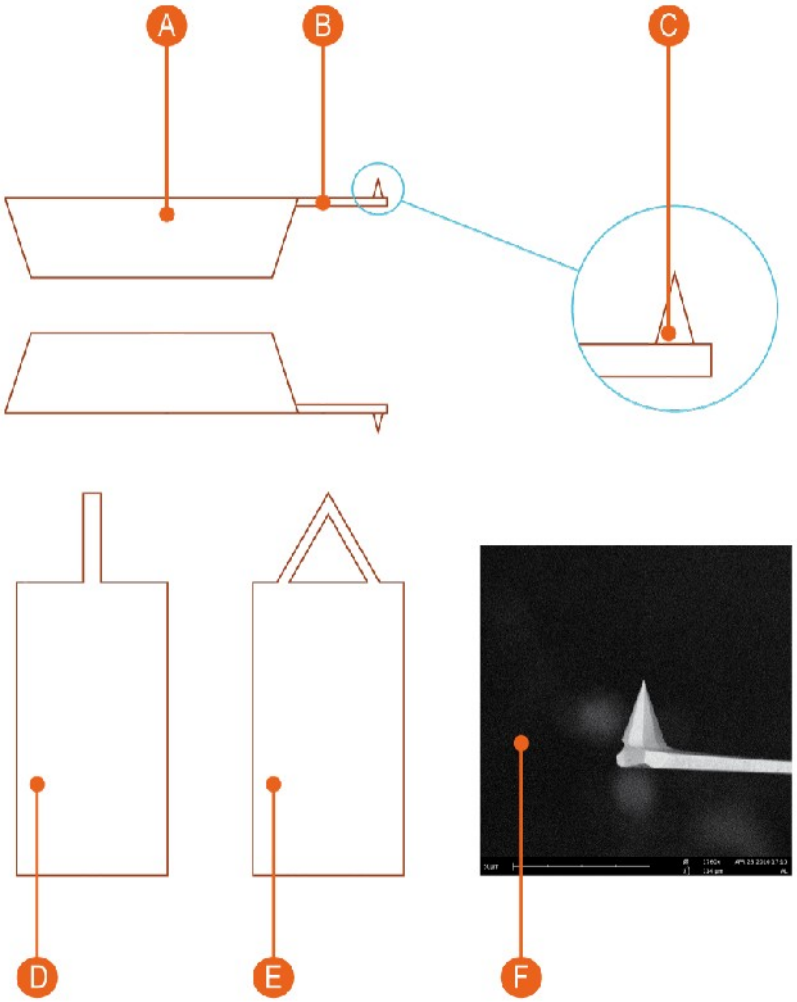
Resolution and accuracy of mapping elements on the surface depends on the corner radius of the probe and the cone angle. Maximum height difference on the surface available for display depends on height of the probe. Coverage probes allow to use

of various techniques of scanning probe microscopy.

In addition to these parameters on the quality of the image, a set of techniques and the ability to study samples of different nature is influenced by two parameters. This rigidity of the probe or the force constant (N / m) and the resonant frequency of the probe (resonant frequency, kHz).

2.3.2. Probe drawings

In general, probes for scanning probe microscopy can be a needle, but using industrialized methods of lithography and various methods of coating, the probes cab be made with specialized forms (Fig. 2.10).



A	Chip
B	Bulk
C	Tip
D	Cantilever with rectangular bulk
E	Cantilever with triangular bulk
F	SEM tip image

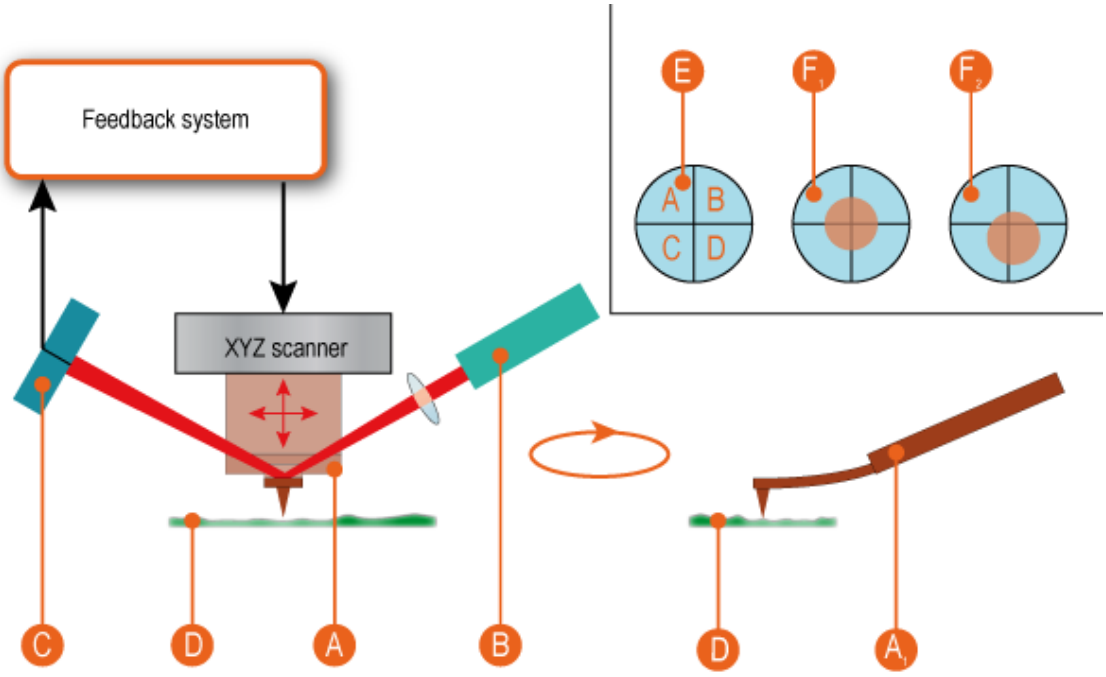
Fig. 2.10 Cantilever tip drawings and images.

2.4. Cantilever Z position detection system

Different registration systems are using to register the movement of the probe and its position relative to the surface. For atomic force microscopy, two types of registration systems are using.

2.4.1. Deflector registration system.

The most common registration system based on laser deflectometer. Schematic diagram of the system shown in Fig. 2.11.



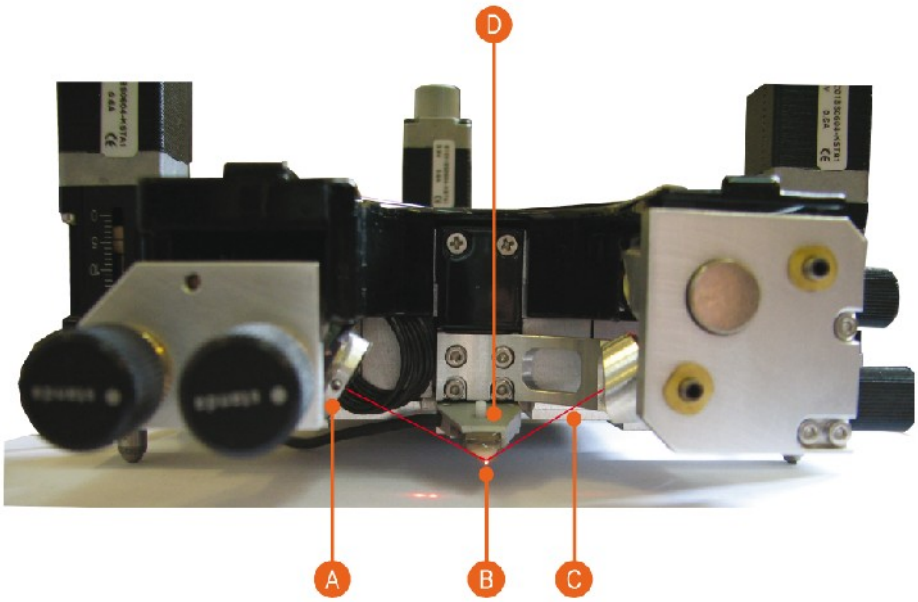
A	Tip.
A_1	Deflection of cantilever bulk.
B	Laser.
C	PSD (Position Sensitive Diode) with 4 sensitive areas
D	Sample.
E	PSD image. Sections is marked A, B, C, D.
F_1	Laser spot position at PSD center.
F_2	Random laser spot position at PSD.

Fig. 2.11 Deflectometer scheme.

The laser beam is focused on the probe bulk. The reflected beam falls on the 4-cell photodiode. On the ratio of the intensity in the sections of the photodiode, position of the reflecting part of the probe in space is determined. When the probe is moved

along the Z axis or rotation of the beam changes the position of the laser spot on the photodiode. As a result, according to predetermined relationships, the position of the probe relative to the surface.

In scanning probe microscope Certus registration system based on deflectometer shown in Fig. 2.12.



A	PSD with 4 cells.
B	Probe (cantilever).
C	laser.
D	Probe holder and scanner.

Fig. 2.12 Deflectometer system in SPM Certus head.

PSD with laser spot is shown in Fig. 2.13.

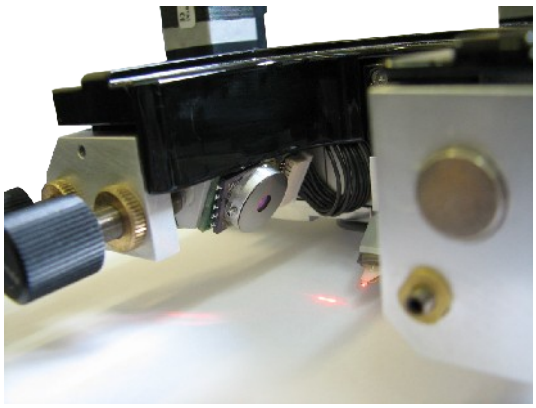
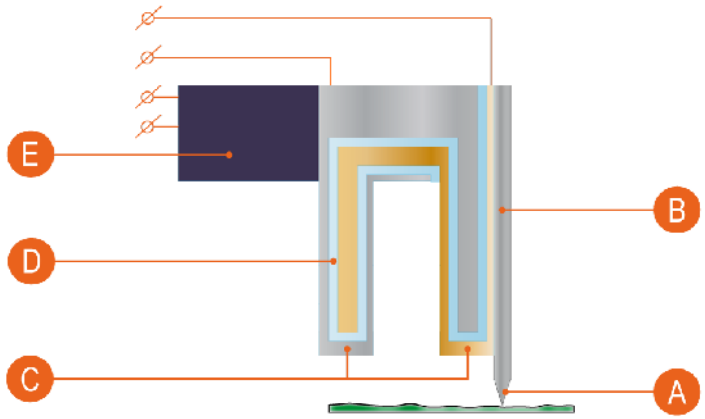


Fig. 2.13 PSD.

2.4.2. "Shear-force" registration system

The method of "shear-force" is based on recording changes in the oscillation frequency of the probe caused by the tangential component of interaction forces between the probe surface. To determine changes in frequency tuning fork resonators used type (tuning-fork, Fig. 2.14), with fluctuations which are detected by a direct piezoelectric effect of quartz crystals.

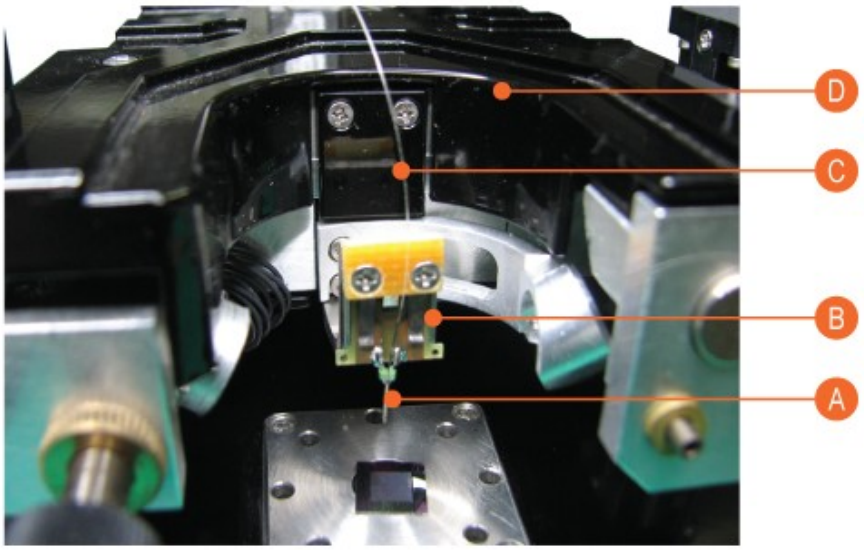


A	Probe tip.
B	Probe.
C	Electrodes that are used to measure voltage changes occurring on the sides of a quartz crystal (direct piezoelectric effect) due to changes in frequency during the interaction with the surface. Information about the change of voltage to determine the current frequency of the resonator.
D	Quartz crystal (piezoelectric).
E	Piezoelectric Driver. Used to create a forced oscillation of the cavity (setting the initial frequency of the resonator).

Fig. 2.14 "Shear-force" registration system.

This registration method is used in cases where it is necessary to avoid interaction of the substance of the sample with a laser beam, or in systems of near-field microscopy.

In the case of near-field microscopy instead of needles on the probe type of "tuning-fork" establish a dedicated probe for near-field microscopy using a specialized probe holder (Figure 2.15).

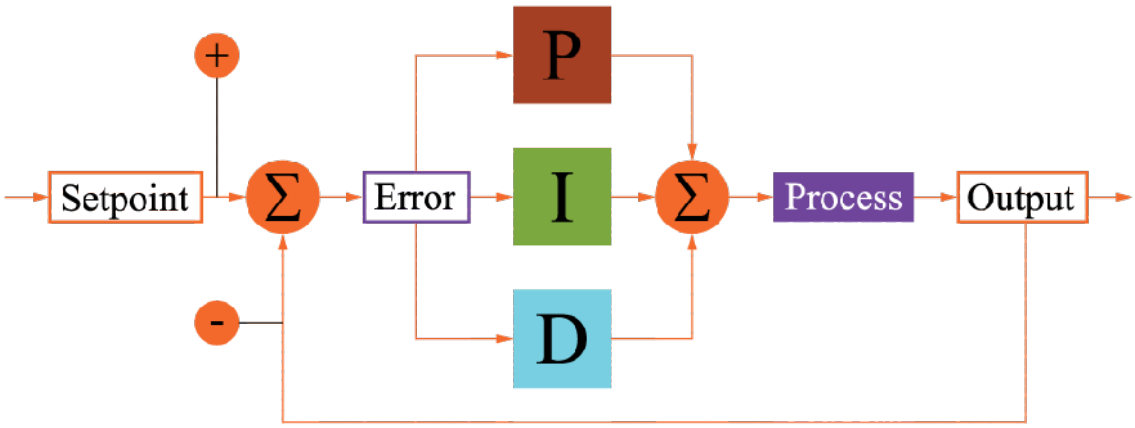


A	**«Tuning-fork»** type probe
B	Probe holder
C	NSOM fiber.
D	**Certus SPM head**

Fig. 2.15 “Shear-force” registration system.

2.5. Feed Back

To generate the control signal is commonly used proportional-integral-differential (PID) controller (see the scheme 2.16) in the feedback loop of scanning probe microscopes.



P	The proportional component of the signal is proportional to set point error.
I	An integral component is used to smooth out the statistical errors in the input signal.
D	Differential component needed to predict the controlled variable deviations.
Setpoint	The set value of the controlled variable.
Error	The difference between the actual and set value of the controlled variable.
Process	Controlled process.
Output	Out form the process sensor.
+/-	The sign of the term to calculate the difference between the actual and set value for actual value.

Fig. 2.16 PID control.

PID controller generates a control signal based on the components of the proportional signal, the integral of the input signal and the derivative of the input signal.

3. Start operation

3.1. SPM Certus installation

To install the SPM Certus, scanning head Certus, SPM controller series EG-3000, the holder of probes, cable kit, computer are required.

3.1.1. SPM Certus head description

Initially, you must arrange scanning head on a hard flat surface (Fig. 3.1).

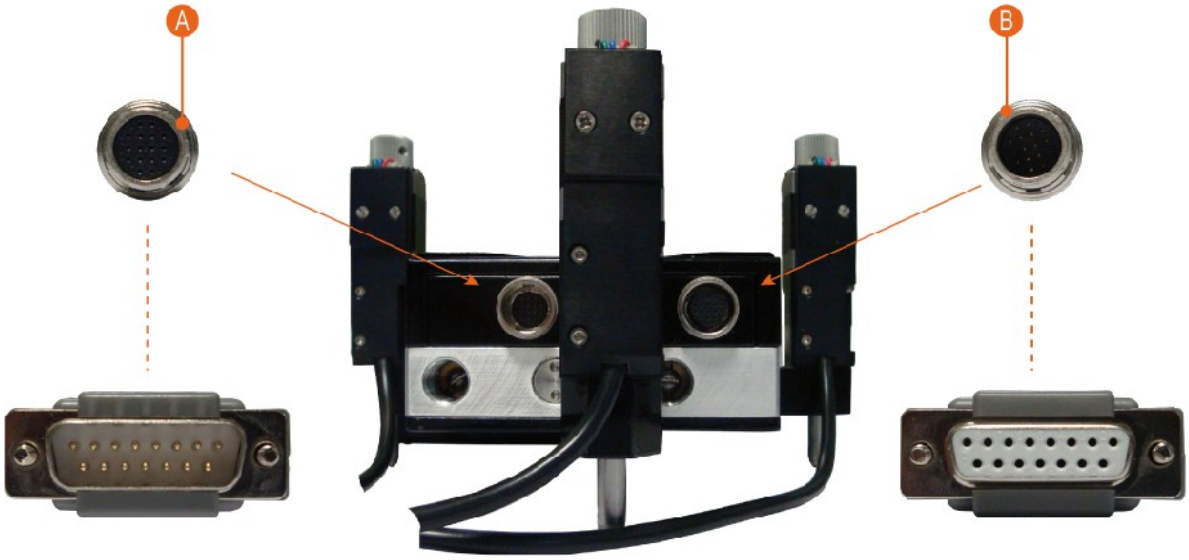
A	XYZ scanning system.
B	Stepping motors.
C	Stepping motors cables
D	Screws for laser beam to cantilever bulk alignment.
E	Screws for reflected laser beam to PSD diode alignment.

Fig. 3.1 Certus scanning head.

The SPM head Certus needs to connect cables for high voltage signals and digital interface, analog signals cable and power (Fig. 3.3).

Fig. 3.3 Scanning head signals cable.

Additional cables are connected to the back side of the head (Fig. 3.4).



A	High voltage cable and digital interface cable.
B	Analog signals cable and power.

Fig. 3.4 Connections diagram.

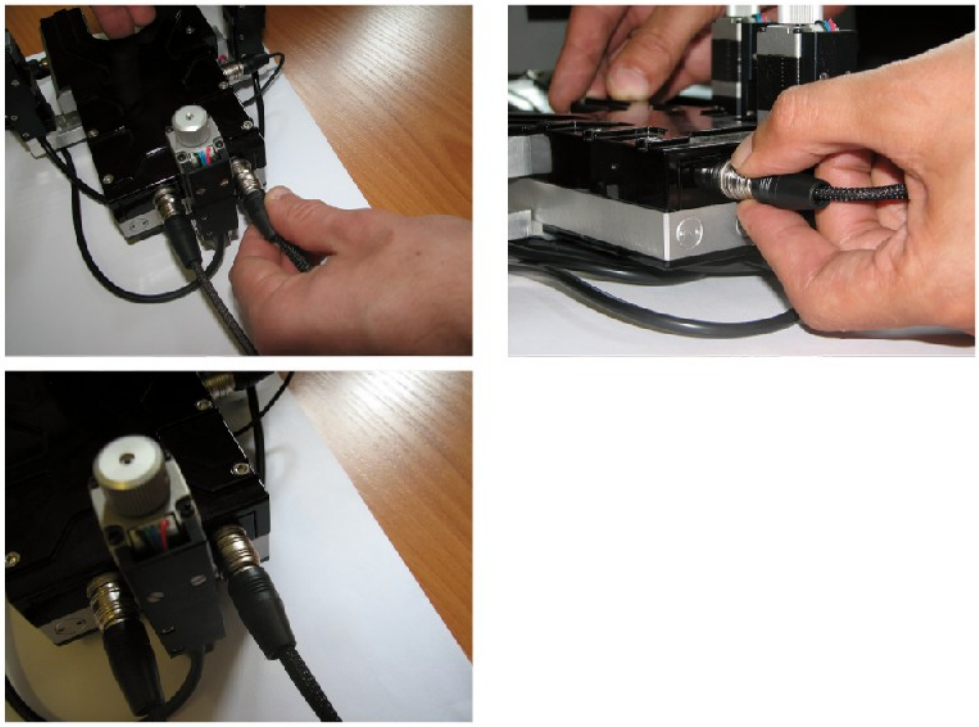


Fig. 3.5 Scanning head cables connection.

Cable plugs are designed so that they can be connected only one way. To do this, connect the plugs and gently rolling to determine the position where we can close the connectors on the head and tail.

Probe holder connector is located at right head side (Fig. 3.7).

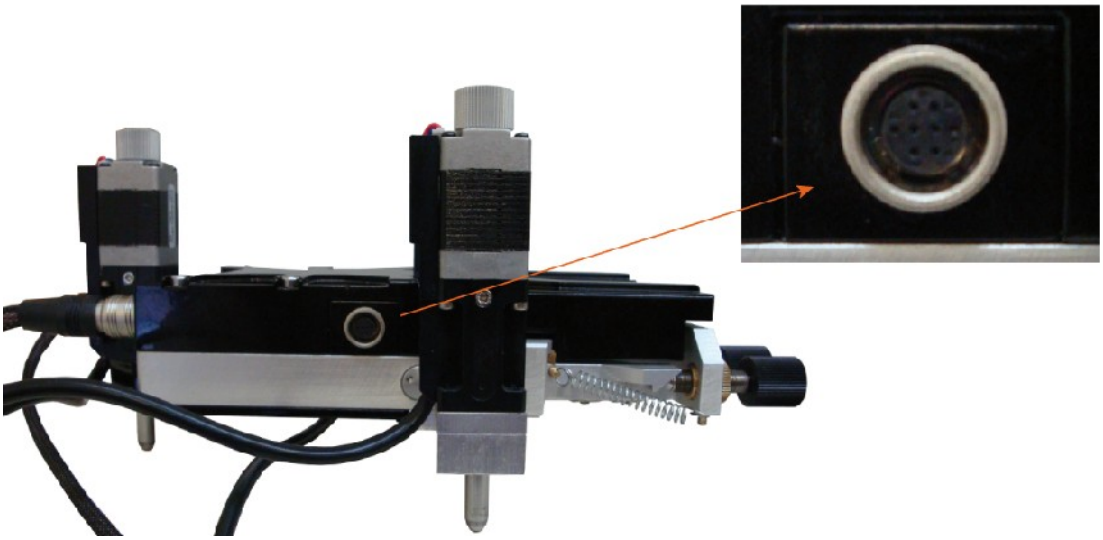


Fig. 3.7 Connector for the probe holder.

Probe holder plug connects to a similar manner.

3.1.2. Probe holder connection.

Probe holder must be connected to scanning head(Fig. 3.8). Regardless of the mode of a scanning probe microscope, the principle of holder connecting is same

Fig. 3.8 Probe holder.

The holder is attached to SPM head with magnetic tablets. Appropriate mounting is located on the bottom of the head. To fix the holder of the probes it is necessary to move to the corresponding fastening the SPM head and install the appropriate slot.

To prevent damage of the probes after their installation is recommended initially install the holder on the AFM head, and then connect the plug to the jack on the head (Fig. 3.9).

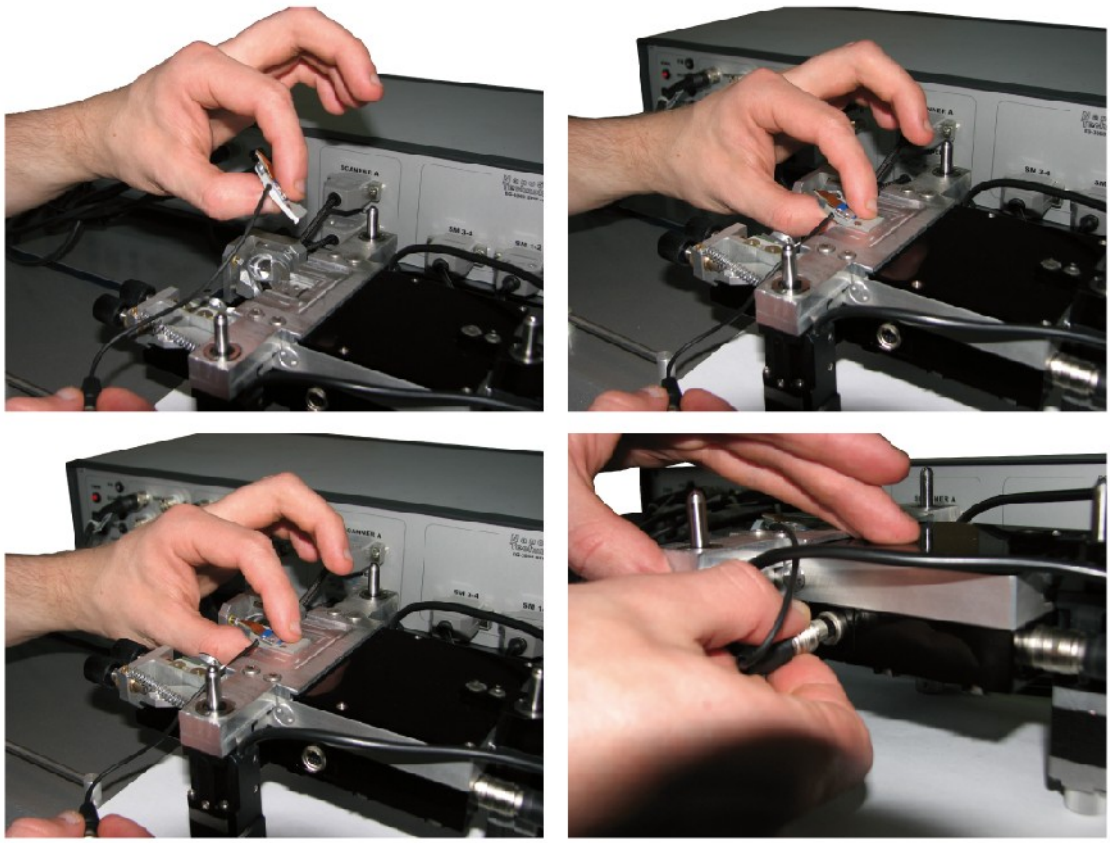
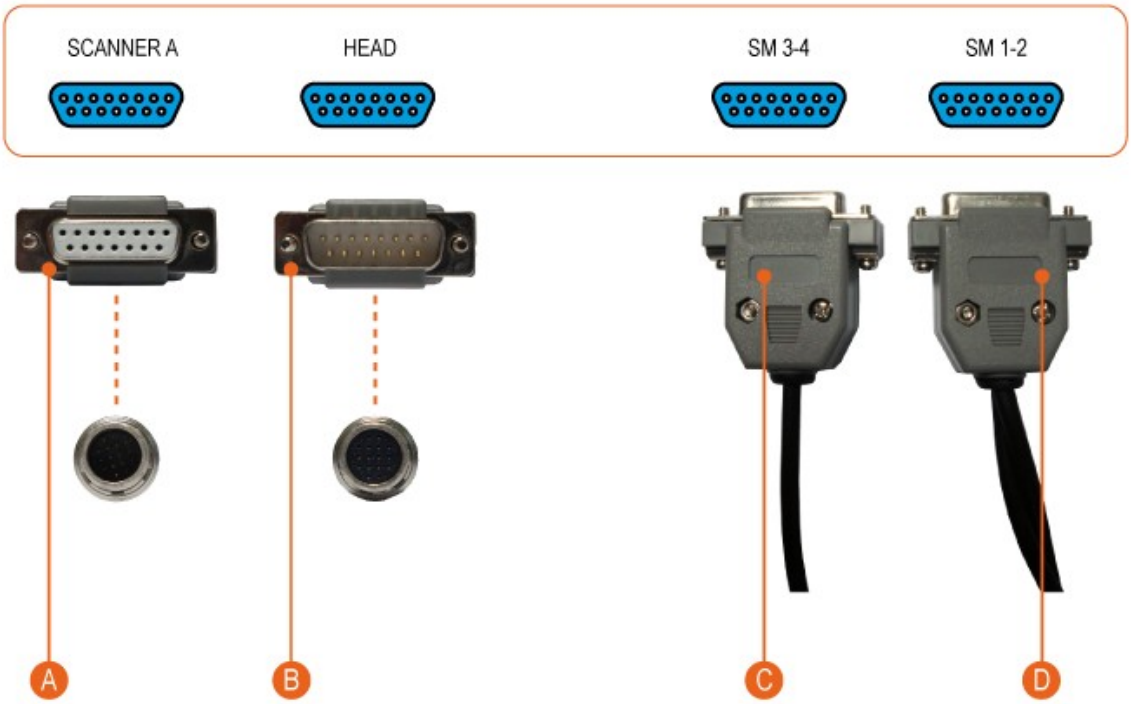


Fig. 3.9 probe holder mounting.

3.2. EG-3000 controller connection

After connecting all cables and installation of the probe holder, scanning head must be connected to SPM controller EG-3000 series.

Pin and connectors description are given in Figure 3.10. A complete description of the connectors on the controller front panel there is in the SPM controller EG- 3000 User Guide.



A	Piezo stacks high voltage and displacement sensors digital interface.
B	Supply voltage and analog signals.
C	Back stepping motor connector.
D	Side stepping motors connector.

Fig. 3.10 Certus scanning head and EG-3000 controller correspondents.

3.3. PC connection

After scanning head connection to the controller, it is needed to connect the USB controller to your computer. Certus scanning head has no direct connection to the computer.

In this case, the computer must have installed software to control SPM system, and USB driver. USB driver will be installed automatically by Window 7 after connecting to controller. If no, you need to install driver you by self, drivers is located in folder drivers.

3.4. NSpec software installation.

Before working with the program NSpec, an archive containing the program files, you need to unzip to a local or removable drive.

Installation is not required. The program runs directly from the *.exe file.

To work with the program is to start by double clicking the left mouse button or file **nst.exe** or **NSpec_№.exe** in the folder **Soft_Package_ №**. The example in Fig. 3.11.

When you run **nst.exe** or **NSpec_ №.exe** will run the program (Figure 3.12).

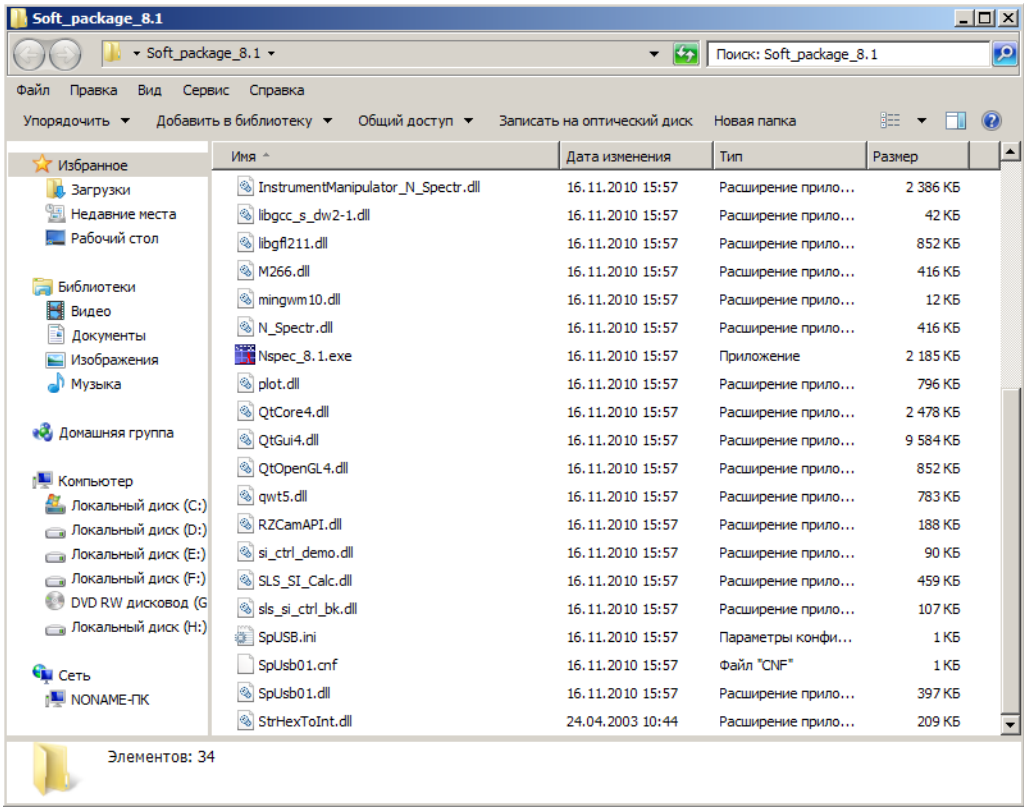


Fig. 3.11 NSpec running.

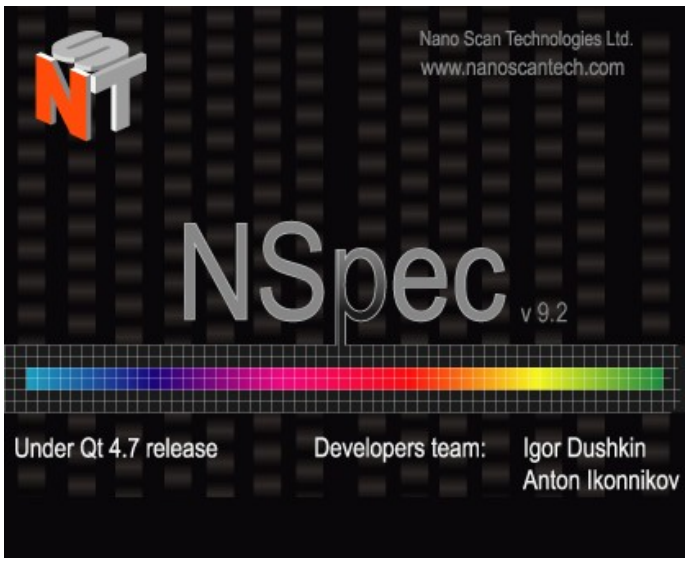


Fig. 3.12 NSpec running.

After performing the above action, main window NSpec displays.

Following the withdrawal of the main window on the screen you can start working with the program and connected equipment.

A detailed description of the program NSpec is given in software NSpec user's guide.

3.5. SPM Certus «on/off» regulation

3.5.1. «On» rules

- Turn PC power «On»;
- Run PC;
- Run NSpec software;
- Turn controller power «On»;
- Check system functionality.

In the case of correct connection of the controller, in the upper right corner of the main window, NSpec SPM controller connection indicator appears as:

.

The indicators on the front of the SPM controller means:

1	PWR	Power indicator
2	USB	USB data transfer indicator
3	FNC	Service indicator
4	RDY	Stand By indicator
5	SCN	Scan indicator
6	FB	SPM Feedback status indicator

3.5.2. «Off» rules

- Stop scanning;
- Save data (if needed);
- Move up scanning head from sample to avoid tip damage.
- Close NSpec software;
- Turn controller power «Off».

4. SPM Certus operation

To get started, you must enable scanning probe microscope Certus. This section describes the operation modes of scanning probe microscope. For other methods, look additions to the user manual. Before reading this section, we suggest reading the software NSpec user manual.

4.1. Probe mounting

Before you start, you must install the probe into the probe holder shown in Figure 4.1.

Fig. 4.1 Probe Holder.

Probes or cantilevers are stored either in the form of plates on which to break off before the work of individual probes, or already prepared for work in special containers (Fig. 4.2). Usually, cantilevers tips directed toward the cover package.

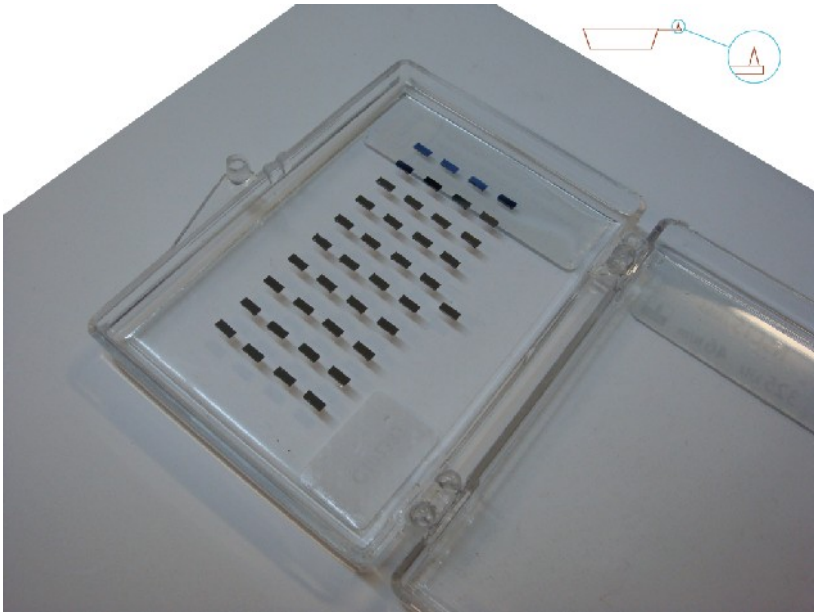


Fig. 4.2 Cantilevers in gel-park boxes.

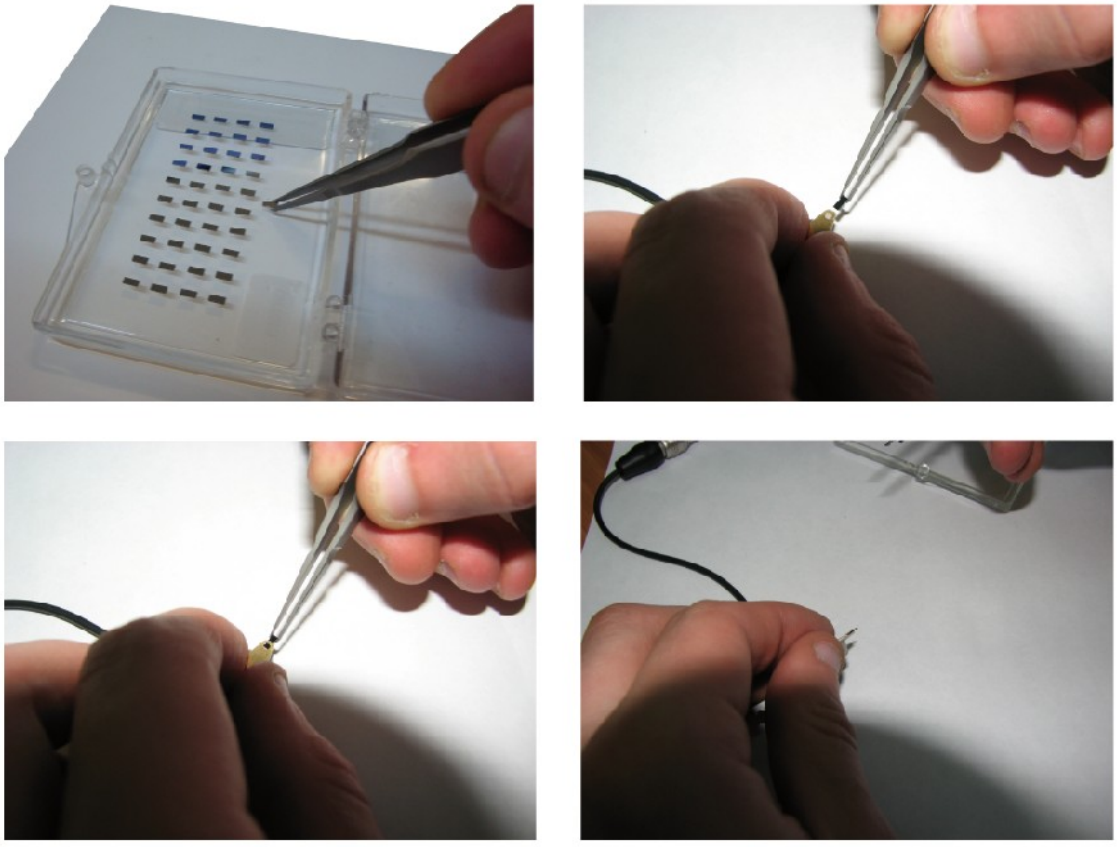
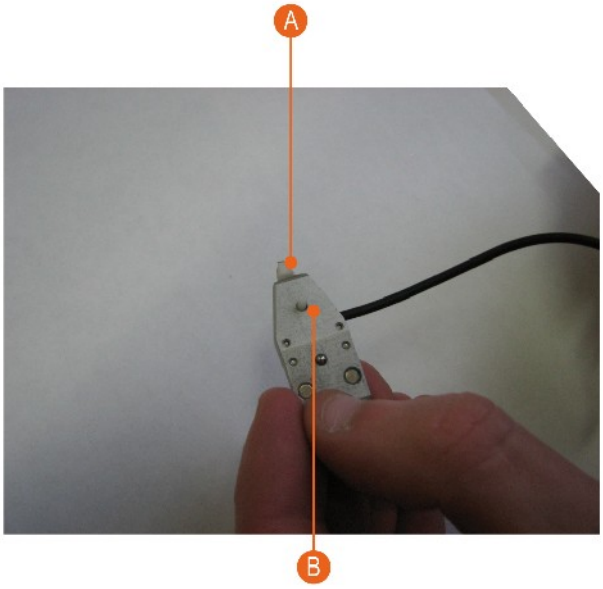


Fig. 4.3 Cantilever mounting to holder.

Installation procedure:

- use tweezers to capture probe for the side surfaces so that the bulk with the tip was directed toward the hand;
- probe holders have to be turned over and pressed to the surface to reveal clip so that the button was pressed on the upper side of the probe holder (Fig.4.4);
- Mount probe to holder;
- Release the probe fix button ;
- Mount probe holder to scanning head with p. 3.1.2.



A	Probe.
B	Spring knob.

Fig. 4.4 Probe mounting.

4.2. Deflectometer system adjustment

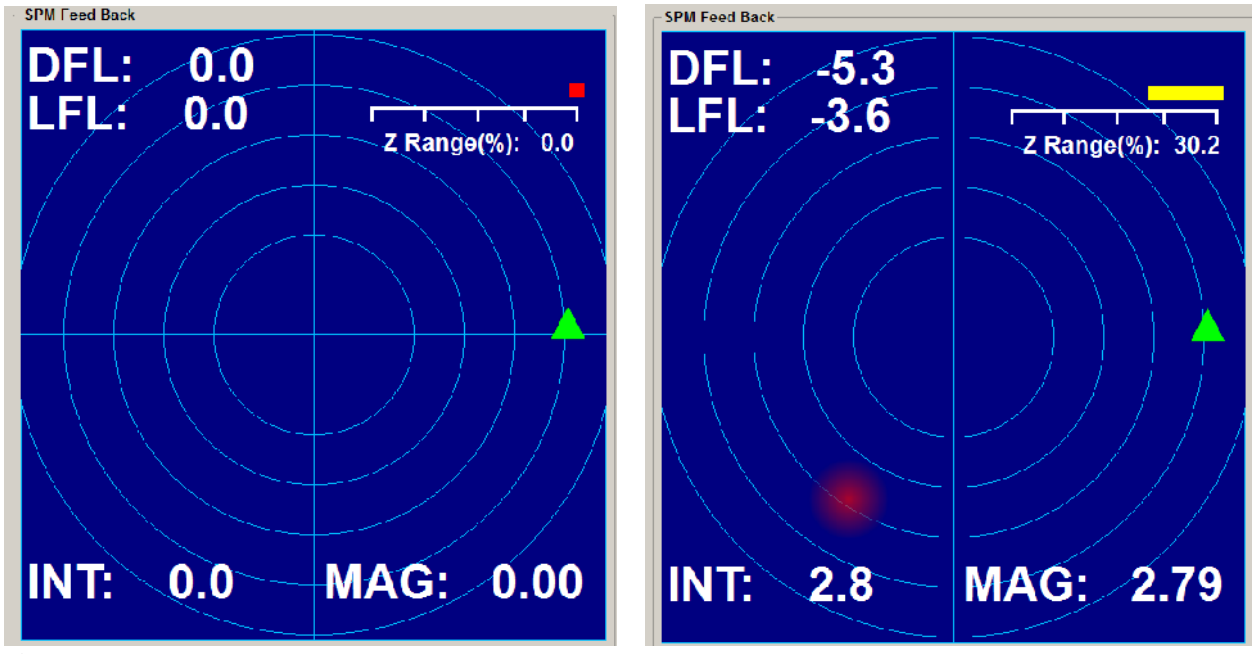
Initially, you must configure the system of probe deflection. To do this:

- Align laser beam to cantilever bulk;
- Align reflected from bulk beam approximately to PSD center;
- Find appropriate parameters for resonant mode;
- Ger probe resonant curve.

4.2.1. Laser beam alignment to cantilever bulk

Procedure:

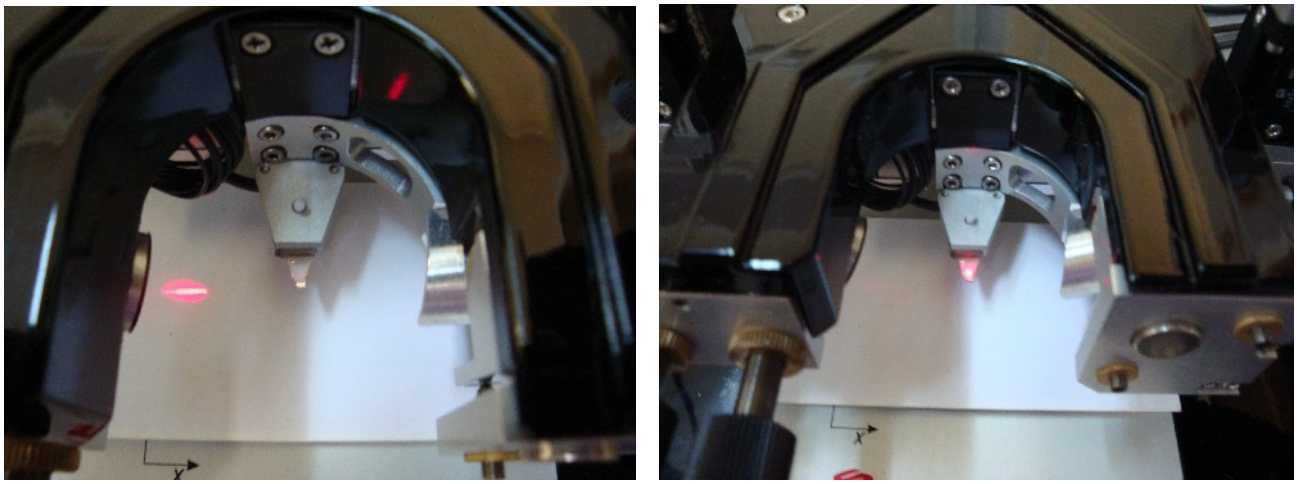
- Open SPM window in NSpec software;
- Define current system configuration. Two different choices is shown at fig.4.5
- Align laser beam to cantilever bulk.



a) b)

Fig. 4.5 a) Not aligned system; b) Aligned system.

In the case of fully disaligned registration system, laser beam may come out cantilever bulk or come to the probe holder (Fig. 4.6).



a) b)

Fig. 4.6 a) out of cantilever chip; b) Laser spot located at holder.

In this case, using the positioning screws, make coinsidience laser beam with cantilever bulk (Fig. 4.7).

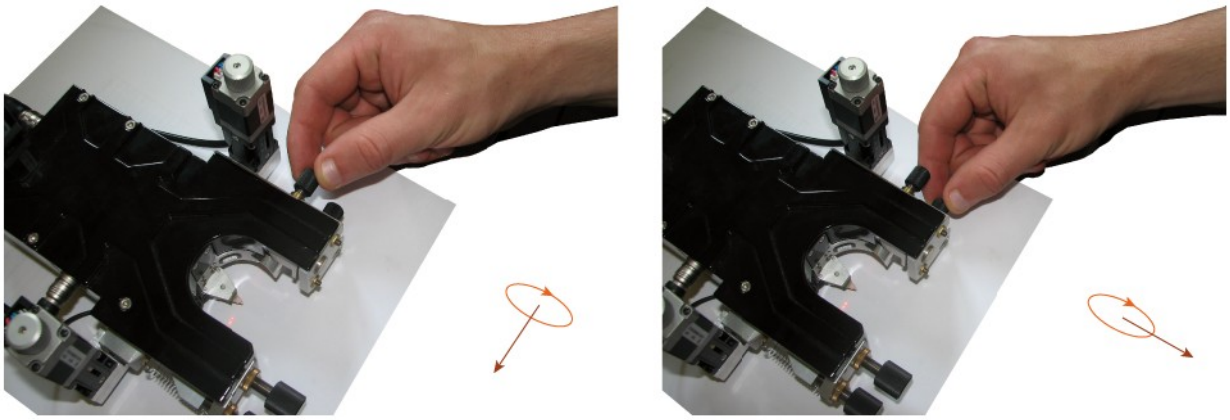


Fig. 4.7 Compliance of the direction of rotation with direction of laser spot travel.

In case of contact of the laser beam with cantilever bulk, diffraction pattern will be clearly visible (Fig. 4.8).

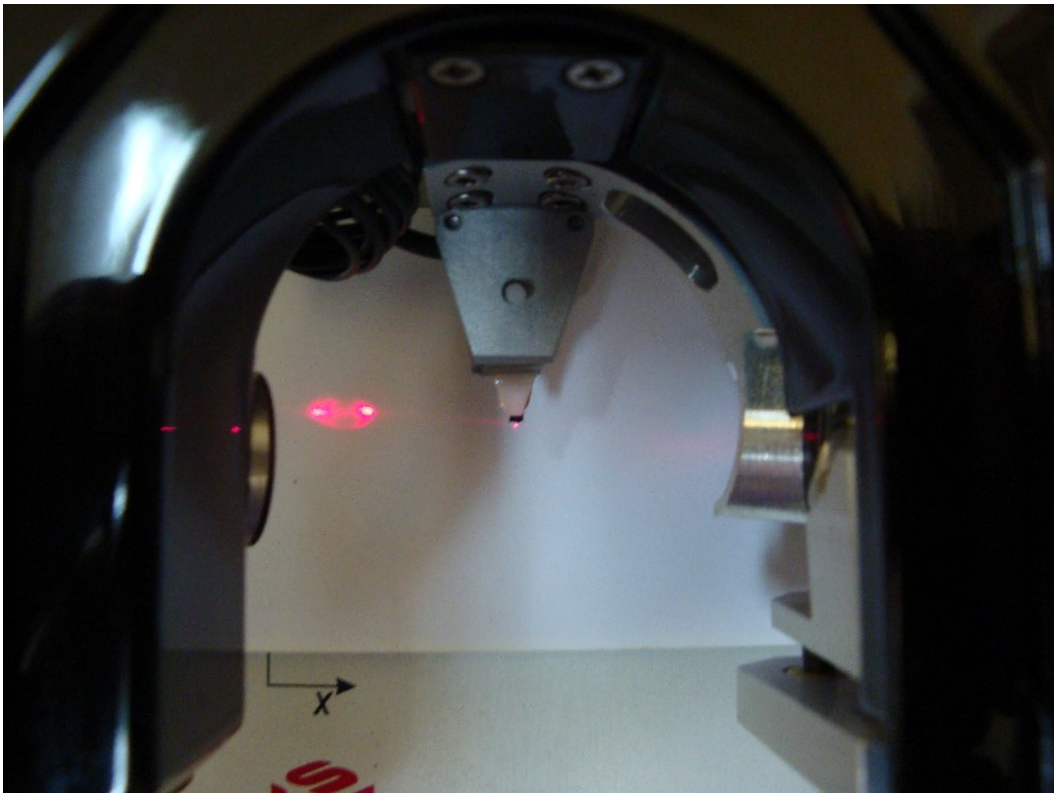


Fig. 4.8 Laser beam aligned to bulk and diffraction pattern is clearly visible.

4.2.2. PSD (position sensor diode) alignment

You have to align reflected laser beam from bulk with center PSD, to do this you can use PSD positioning screws (Fig. 4.9).

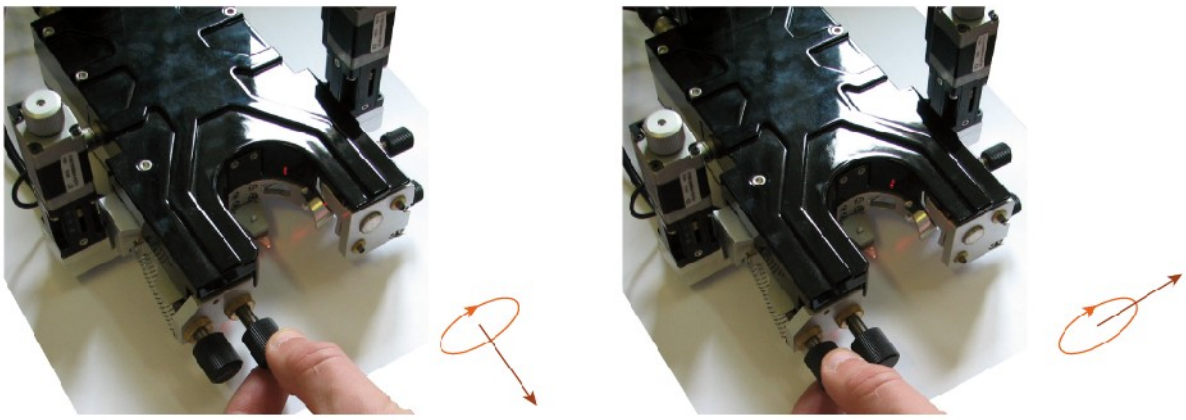


Fig. 4.9 Compliance of the direction of rotation with direction of PSD travel.

SPM Feed Back window shows laser spot position at PSD and it's intensity.

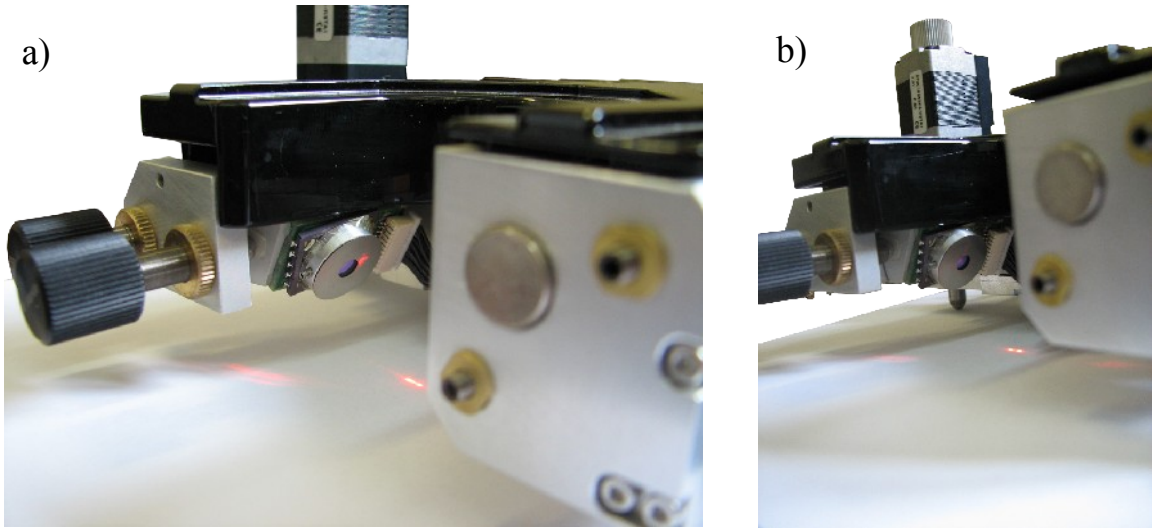


Fig. 4.10 a) reflected beam is out of PSD; b) laser beam is within PSD area.

4.2.3. Reflected beam maximum intensity finding

Once the SPM Feed Back window will display the signal from the photodiode is necessary to find the maximum reflection from the bulk. Red sphere size corresponds to laser spot position and its intensity, during alignment must be on a blue field (PSD area) (Figure 4.11).

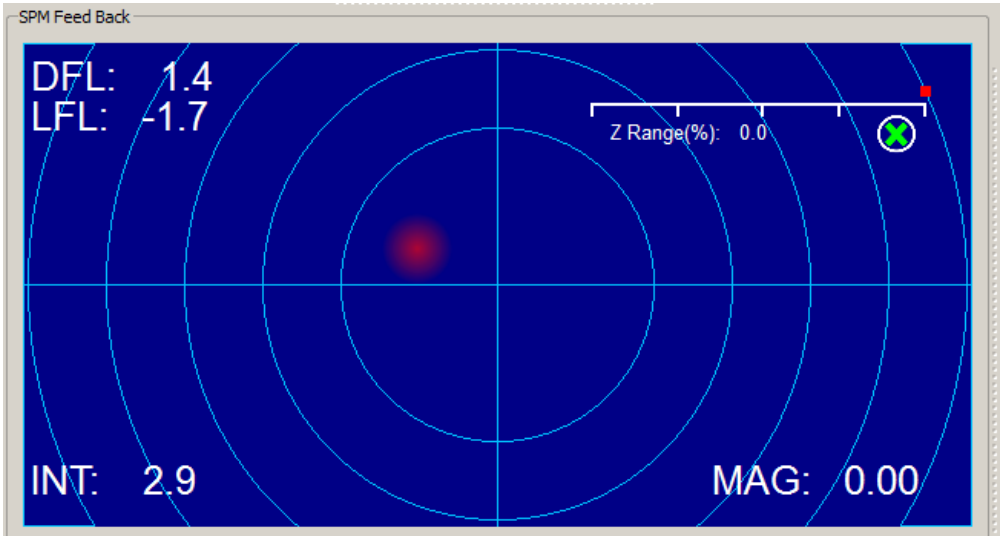


Fig. 4.11 PSD signal.

Using laser beam alignment screws, try to get signal maximum(fig. 4.12.).

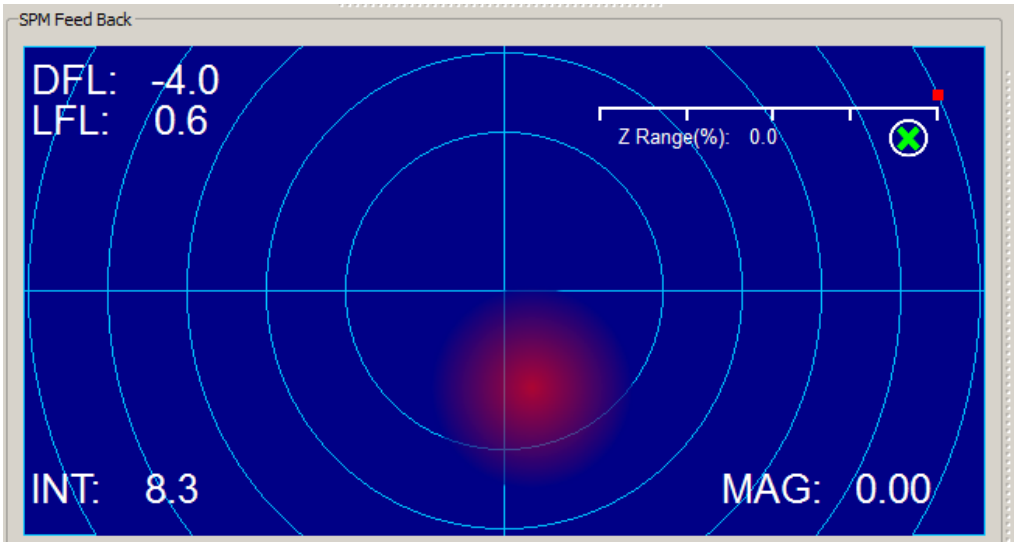


Fig. 4.12 Signal maximum.

4.2.4. Reflected beam alignment to PSD center.

After finding the maximum of the reflected signal is necessary to combine the center of the laser spot to the center of the photodiode.

To do this, use the positioning screws of the photodiode to move the laser spot in the center of the SPM Feed Back window and obtain close to zero values of indicators DFL and LFL as possible. (Figure 4.13).

In the drop-down menu beneath the SPM Feed Back should be set OFF.

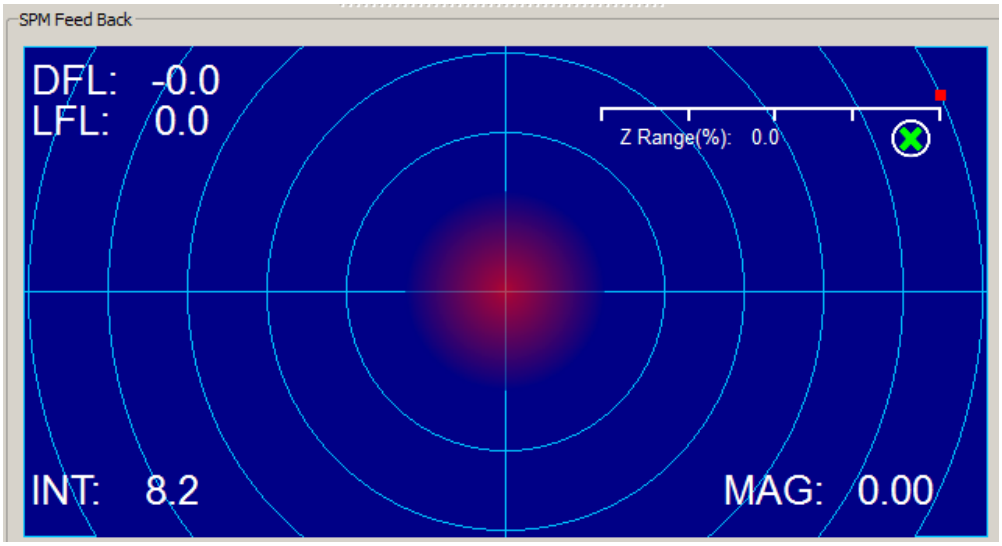


Fig. 4.13 Laser Beam is in the PSD center.

4.2.5. Probe resonant frequency acquisition.

After finding the maximum of the reflected signal and overlapping centers of the laser spot and the photodiode, in the case of contact mode, you can proceed to feedback parameters settings and approach of the probe to the surface. In the case of non-contact methods, you should find the resonant frequency of the cantilever. For non-contact methods in the field FB Input Signal (SPM Mode) must be set to Probe Magnitude – Tapping Mode.

Required steps:

- in the Scan window SPM, in drop-down list Channel, choose the MAG (Fig. 4.13);
- set the search range of frequency from 0 to 500 (or in the case of cantilevers with a large resonant frequency is greater);
- In the Input Gains set all values of multiplier equal to 1;
- Set Drive Intensity slider value equal to 1;
- Press Run.

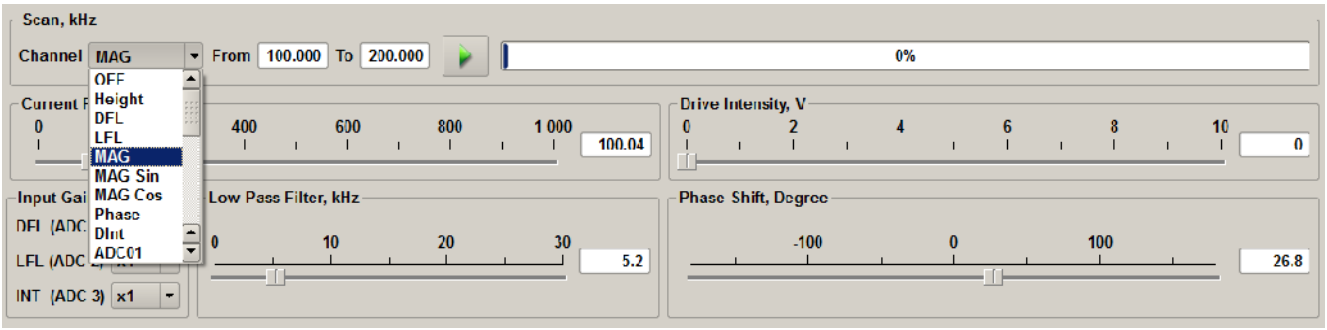


Fig. 4.13 Probe resonant data.

After that, Plot will show the current resonant curve of the cantilever (Figure 4.14).

If you know roughly the resonance frequency value of the cantilever, search range can be narrowed (Figure 4.15).

If necessary, resonant frequency can be set manually (Figure 4.16), using obtained resonant curve.

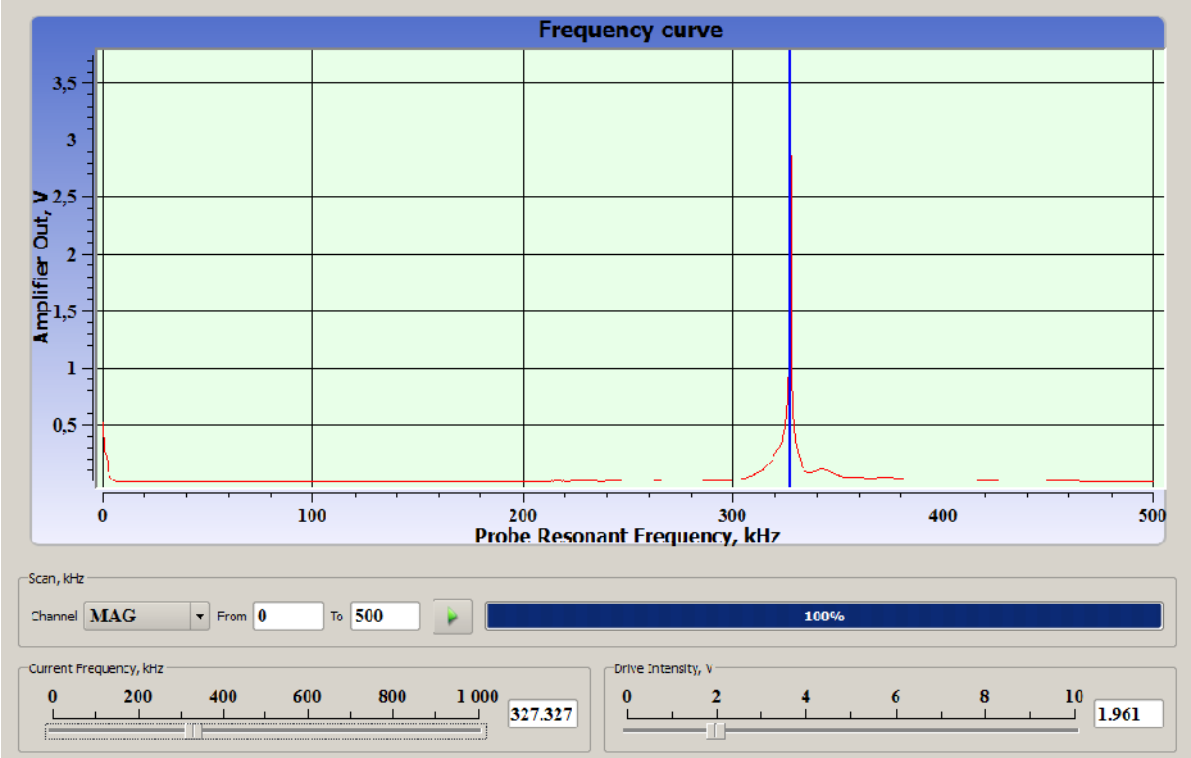


Fig. 4.14 Cantilever resonant frequency acquisition.

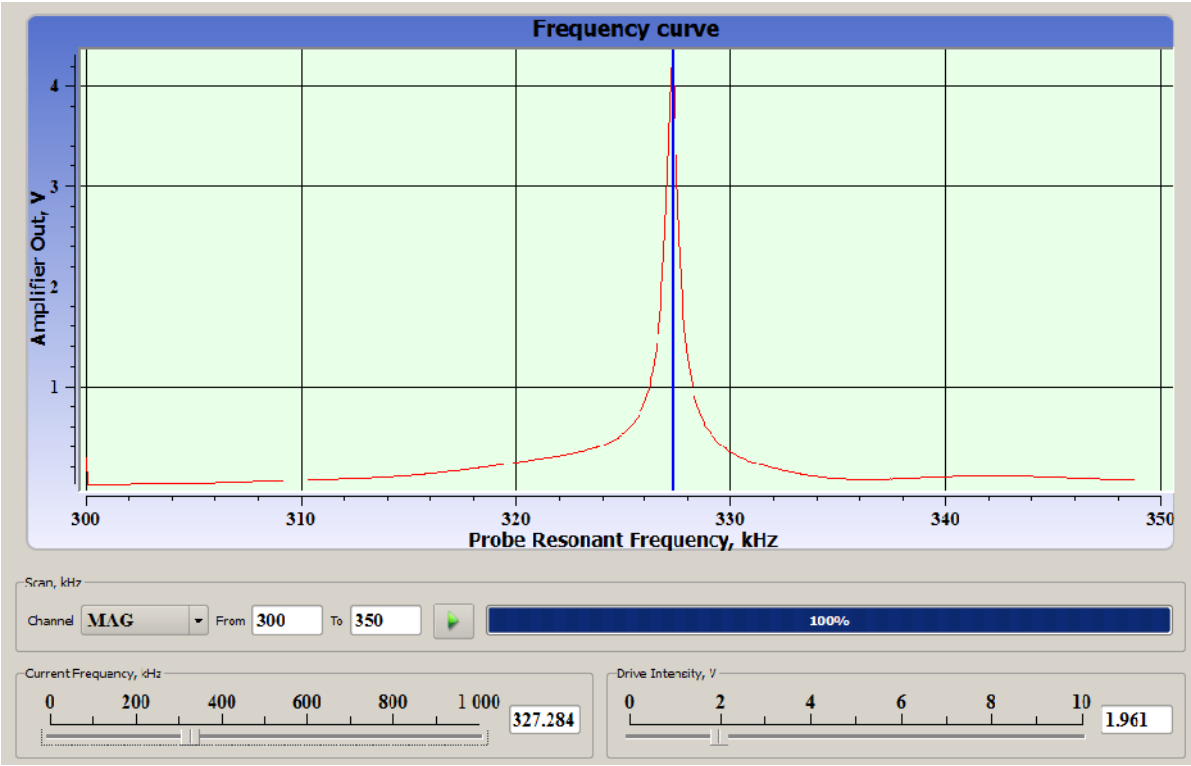


Fig. 4.15 Cantilever resonant frequency acquisition.

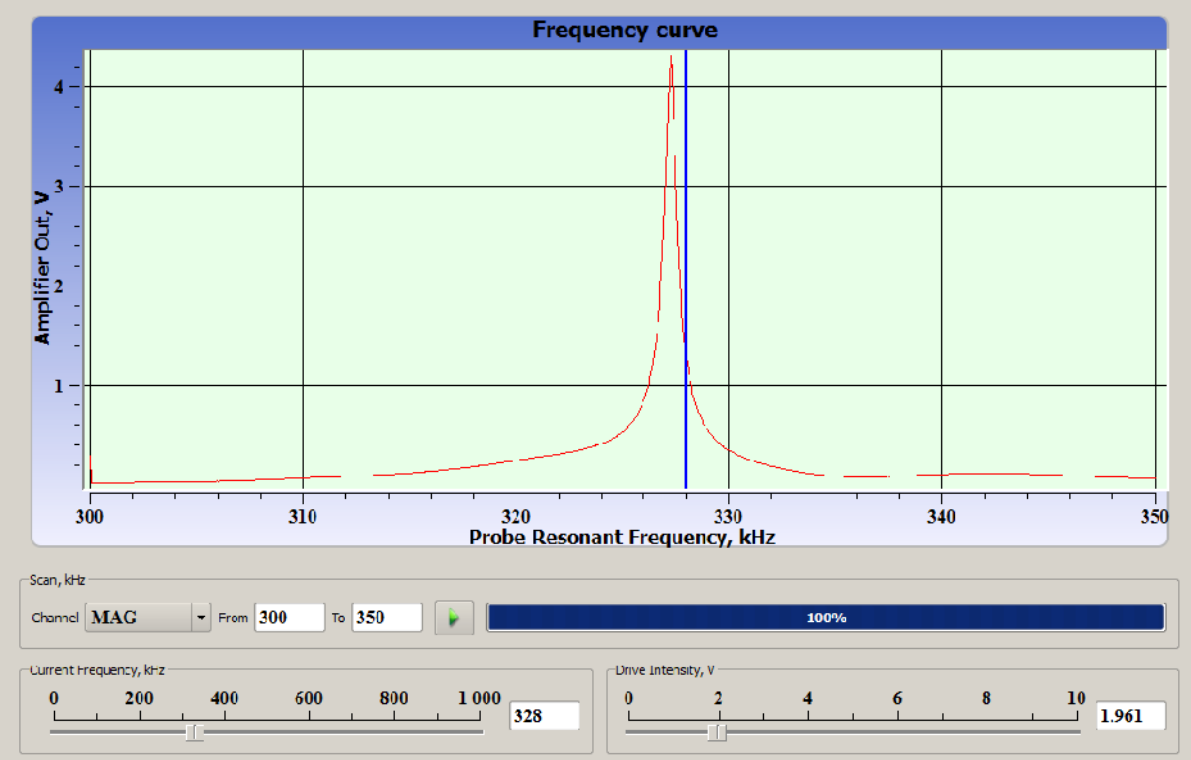


Fig. 4.16 Cantilever resonant frequency manual set.

Generally, it is necessary to achieve the resonant frequency of 1 V in the absence of information about the properties of the sample. Take this value as reference value.

4.3. Feedback tuning

To control feed back parameters (PID regulator for Z probe positioning), you can use sliders FB P, FB I, FB D, Set Point in SPM or in tab FEEDBACK (SCAN window), more derailed information you can find in par. 5.1 Software user manual.

Set all PID parameters to 1, when sample is unknown. After some images acquisition, using data you can change feedback parameters.

The maximum value of the feedback is determined by the beginning of the feed back signal oscillations, with large amplitude and short period during the installation of the probe at a point. Oscillation may occur at the same parameters for different samples. For each type of sample selection of the feedback parameters is different. Basicly, the "softer" surface sample and the larger difference in height, parameters of the feedback should be the bigger. The same is for the influence of noise and external vibrations. You must adjust the parameters FB P and FB D.

For "hard" materials, with a relatively small difference in altitude (a few tens of nanometers) on small scan areas, feedback parameters can be set are close to 0. For example from 0,1 to 0,3.

At high scanning speeds for any of the samples are recommended to set the parameters of the feedback of more than 1. Nearly to the values near the onset of oscillation in the feedback loop.

4.4. Set point tuning

After setting the resonant frequency and amplitude, and feedback parameters, using the value of MAG in the field of SPM Feed Back, set in the FB INPUT SIGNAL (SPM MODE) sets the setpoint value for the feedback. For the assessment scan is recommended to install 50% of the current value of MAG. Normally, value is depends on the surface characteristics of the sample.

4.5. Tip to sample approach

4.5.1. Rough approach

For rough approach, use functions described in the software NSpec user manual, Section 4.3 stepper motors.

4.5.2. Scanning head tilting

In some cases, it is recommended to scan with the probe tilted at a certain angle to the surface, or to compensate for the slope of the surface samples. Use individual control of each stepper motor by the algorithm:

- Move down head roughly in the 5-10 mm from the highest point of the SPM head;
- Go to the stepper motors control menu with each individual control (Section 4.3.1 software NSpec manual);
- Move up to a maximum SPM head rear stepping motor;
- Return to the option of all motors control;
- Start rough approach to sample.

Use rough approach till approximately 3 mm from the surface. Decrease approach speed for closer distance.

4.5.3. Tip landing.

After the implementation of the rough approach is necessary to switch on feedback (section 4.4. software NSpec manual). And the press Landing.

Upon reaching the surface, and the magnitude of the oscillations of the probe equal to the specified value approach process will stop.

Next, you need to verify the absence of oscillations. You must open the box OSC curve through a group of instruments Plot Mode Control (Section 4.1 details. software NSpec manual).

4.6. Scan settings.

After tip landing to the surface, open SCAN window. A detailed description of the functions of the window is in the software NSpec User Guide in Section 5.

It is recommended to obtain big overview scan, for correct selection of feedback parameters, oscillation parameters of the probe.

We recommend following parameters for data acquisition with maximum resolution:

- Full scan area;
- Scan size 300x300 pixels;
- Scanning speed 1 line/sec (Hz);
- Signals Height and Phase for forward and backward directions.

After getting the test images, you may select desired scan settings and the interesting area on the surface.

To select the number of pixels in the image should be guided by the following rules:

- For non-contact techniques does not make sense to put the number of points, which is equal to resolution less than the probe curvature radius;
- Scanning speed depends on size of the scanning field for the same number of points. It is recommended to reduce the number of points with decreasing field scan to save the scanning speed in proportion to the size of the scanning field or increase the scanning speed;
- For different sizes of the scanning field may need to change the parameters of the feedback.

4.7. Scanning process.

At the scanning process, in the absence of vibration and acoustic protection, is recommended not to affect scanning probe microscope Certus to mechanical or acoustic impacts This may cause artifacts in the image and even the movement of the sample relative to the microscope, and probe damage.

4.8. Primary image processing and saving

For primary results processing and saving use built-in tools to work with images and graphics.

A detailed description of the location and functions of these instruments is given in the software NSpec user manual in sections:

- Par. 2. Interface tools;
- Par. 3. DATA window.

We recommend you to save data without filters processing and extra filters.

5. Scanner calibration

All SPM scanning and positioning systems use piezoceramic materials. Besides the obvious advantages in terms of accuracy and control of movements of these materials, they have several disadvantages. The main disadvantage is the non linearity.

Nonlinear properties of piezoelectric ceramics is dependence between the control electric field and the deformation of the piezoceramic sample, i.e. non linearity and ambiguity of this relationship. Usually, the nonlinear properties of ceramics are divided into creep, hysteresis and non linearity itself. Nonlinear properties includes sensitivity volatility of the piezoceramic.

Scanner not equipped with sensors, control voltage on the axis is an indication of its position on this axis. Non linearity and ambiguity of the dependence of the control voltage - the situation often leads to significant distortions of the image.

5.1. Piezoelectric actuators properties

5.1.1. Creep

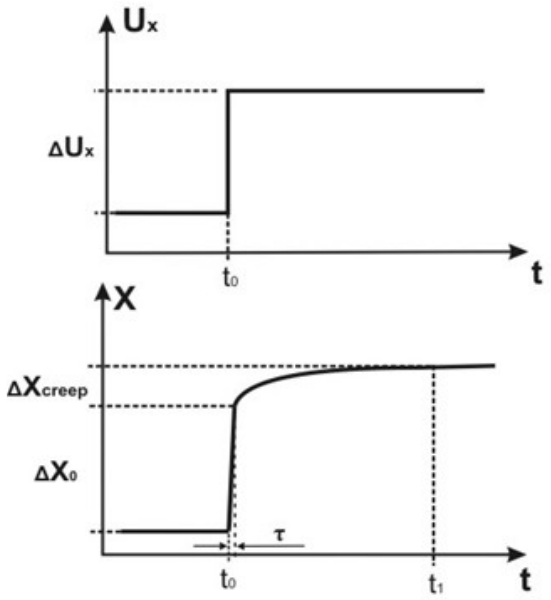


Fig. 5.1Scanner response for voltage step

Creep of the piezoceramic results in the fact that after the change of control voltage, the dimensions of piezoelectric scanner continues to change. For example, after the voltage step supply to the piezoelectric element, there is a long-term drift (Fig.5.1).

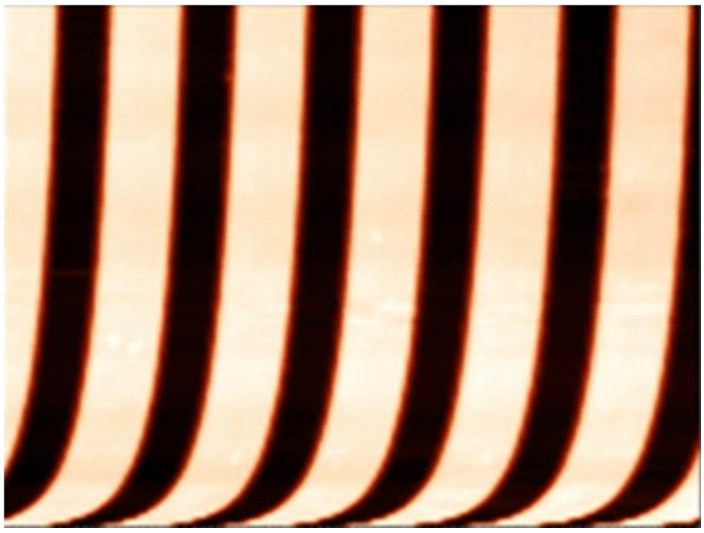


Fig. 5.2 XY Creep.

Creep in the XY plane is well seen after large displacements of the scanning area (Fig. 5.3). When you try to move the scanner at a given point, for example, for vector lithography or nano-manipulation, as well as in selecting the scanning area, creep along with the hysteresis of piezoelectric ceramics is the main source of error.

To determine the creep after the voltage jump (Fig. 5.2), one can use the expression:

$$\Delta X_{creep}(t) = \Delta X_0 \beta \ln \frac{t-t}{\tau} \quad , (5.1)$$

β ~ 0.01 – 0.03, ΔXo – displacement after τ seconds caused by voltage jump (τ ~ 0.1 – 1 sec.). Let suppose β = 0.02, we get: one minute after power surge creep is 8% of the movement in the 1 second, then for every time moment 10 times bigger, 4.6% is added to the initial displacement. Equation (5.1) is true in the time interval of a second to at least several hours. You can use this ratio as an estimation of creep for any other monotone change of control voltage.

Coefficient β for the piezo depends on the value of the control voltage jump. Also there is the dependence of creep on the direction of the jump. So do not expect that, using the formula (5.1), you can enter the exact software compensation of creep in the plane XY.

Each time you run a scan on a slow scan direction, creep is observed. The fact that the scanner was shifted from field center at the starting point, continues to "creep" in the direction of this shift with a decreasing rate. For slow direction the rate of creep more than the average speed during scanning at the initial moment. Outcome of assessment using the relation (5.1) is as follows: speed on a slow direction reaches zero, a time equal to 50xβ% (i.e. about 1%) of the total scan time. After a period of time equal to 10% of the time, creep rate would be 10 times smaller than the average speed on a slow scan direction. Measurements confirm this assessment. Creep does not not make noticeable distortion, we must wait to be scanned 5 - 10% of the entire region, and then restart the scan. A typical example of creep on Z - the distortion of the profile in the measurement step. When filing for the scanner voltage corresponding to a height of the step, the scanner is reduced by a specified distance and then some more time continues to "creep" in the same direction. To save a contact probe with the sample, you must

provide power in the opposite direction. Because the topography is recorded as a signal applied to the Z-element scanner voltage, the measured profile will look like in Fig. 5.4.

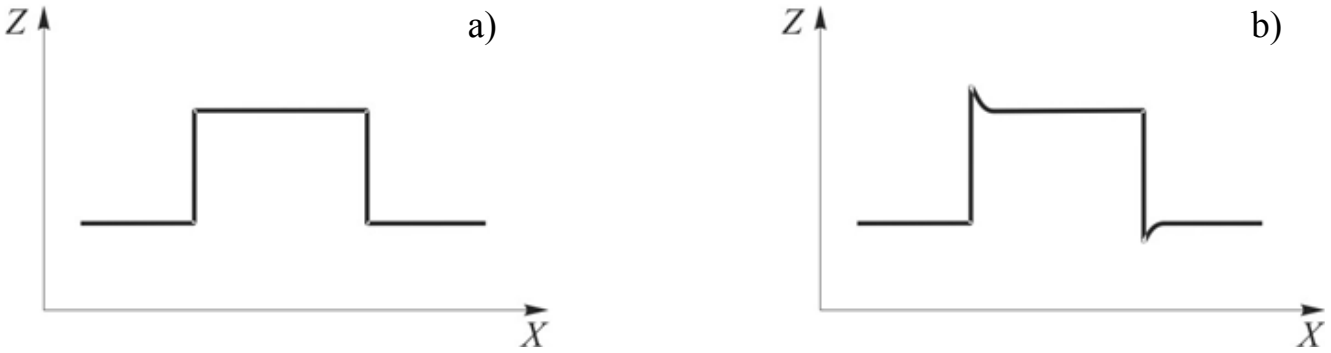


Fig. 5.3 Creep influence to step profile. a) Real profile; b) Measured profile.

For the motion of the scanner under the action of periodically varying voltage, creep causes the displacement rate dependence from voltage rate. For example, when applied to any section of the scanner control voltage is a triangular shape with constant amplitude and decrease the rate of change of voltage, the amplitude of movement of the scanner will increase. Amplitude of logarithmic velocity:

$$S(v)=S_0(1+\beta\, lg\frac{v_0}{v}) \quad , (5.2)$$

v, v_0 – voltage rate, S – displacement amplitude rate, S_0 – velocity amplitude rate v_0.

Investigation of dependence (5.2) are: The range of the scanner in XY and Z at the maximum possible amplitude control voltage depends on the rate of change of voltage. When measuring the topography of the voltage supplied to the Z-section scanner, the height of any object on the sample surface at different scanning speeds are different.

Value (5.2) is used for software correction field size in the XY plane, depending on the speed of scanning.

5.1.2. Non-linearity and hysteresis

In general, the piezo ceramic is characterized by nonlinear dependence of strain on the control of the electric field. This dependence is also ambiguous (hysteresis). Accordingly, the piezo has a non-linearity and hysteresis of the position of the control voltage for each axis. Fig. 5.4 is an example of image distortion caused by non linearity and hysteresis of the scanner along the axis X. The width of the hysteresis loop for the scanner (Figure 5.6) on the axis depends on the control voltage amplitude and properties

of the piezoelectric element. Normal values are 15 - 20% of the scanner range.

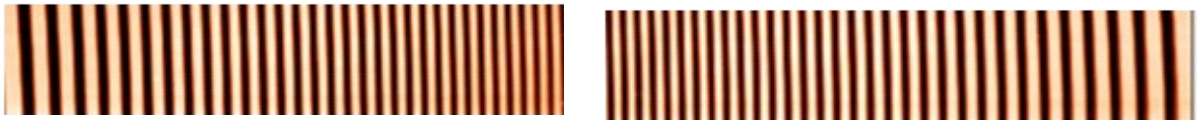


Fig. 5.4 Si grating SPM image (periodicity is – 3 μm), shows scanner non linearity and hysteresis along x axes. Scan size in X – 100 μm. Voltage raster form is triangular. Left image – obtained at forward direction; left – obtained at backward direction..

5.1.3. Scanner hysteresis loop properties

The main properties of the hysteresis loop is used for software scanner nonlinear correction. It is assumed that the scanner is fed periodic control voltage of a triangular shape (as in Fig. 5.8, a).

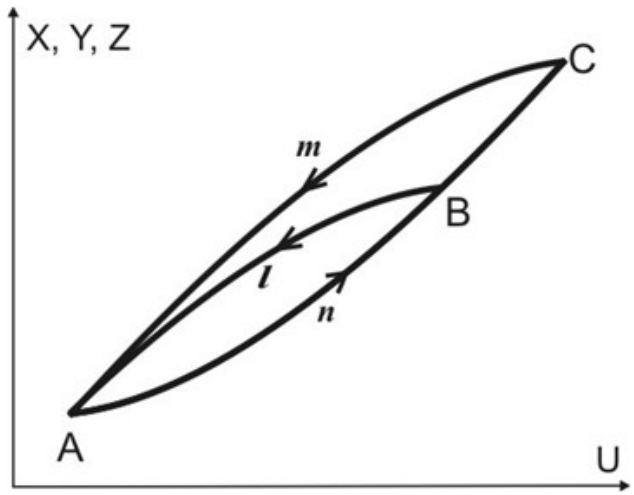


Fig. 5.5 The position dependence of the scanner on the magnitude and direction of the applied voltage.

a). Symmetry. Fig. 5.5 shows two hysteresis loops (AnCmA and AnBlA) for different amplitudes of the piezo control voltage. Branches AnC and CmA obtained from each other symmetry, are about the center of the segment AC, which thus is the center of symmetry of the entire loop. A similar statement is true for smaller loops AnBlA and the center of the segment AB.

b). Shape independence from amplitude variations. At the same rate of change of control voltage branch AnB of smaller loop coincides with the initial section of the branch AnC of larger loops (as in Fig. 5.6).

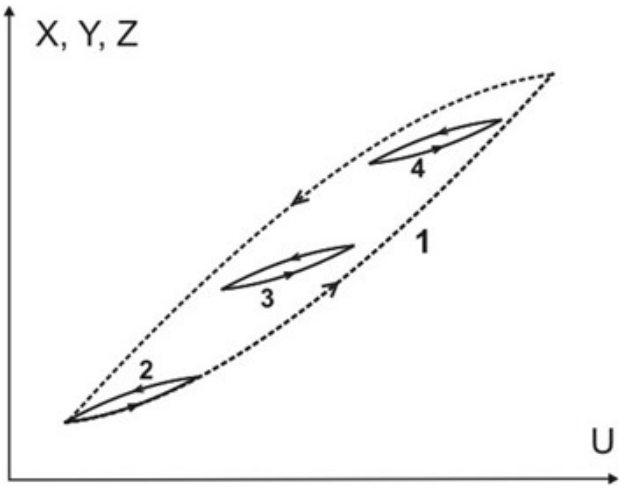


Fig 5.6 Hysteresis loops at different constant components of the voltage.

c). Saving the form when changing the constant component of the control voltage. The shape of the hysteresis loop does not depend on the constant component of the control voltage. Fig. 5.7 shows the hysteresis loop for a maximum amplitude of the control voltage. Depending on how the power supply, the scanner may be

at any point (U, X) inside the loop. Loops 2,3 and 4 were obtained at the same amplitude but different constant components of the control voltage. These loops are the same, the shape of their branches roughly coincides with the initial section of the lower branch of the loop 1.

d). The weak dependence of shape loop on the velocity. A decrease in the rate of change of control voltage in accordance with (5.2) varies the amplitude of scanner movements. At the same time in a fairly wide range of values of speed, we can assume that the hysteresis loop simply changes the scale of the axis of movement.

5.1.4. XY non linearity correction

Fig. 5.8 shows the motion of the scanner at two cases: software nonlinear correction of the axis X on and off. From this figure we can see what's inside your correction algorithm. First, the scanner voltage is a triangular shape (Fig. 5.8, a), in some way measured by its position (e.g. on a test grid). As a result, the relationship of the provisions of this axis with a control voltage X(U). Next, using the inverse relationship U (X) we can calculate the voltage sweep such that the movement in X was linear (Fig. 5.8, b).

Properties b) and c) and d) hysteresis loops allow the use of the dependence U (X) for all sizes and positions of the scanned area, as well as for different scanning rates. Using (5.2) introduces the correction field size of the scanning speed.

Correction gives good results when the following conditions:

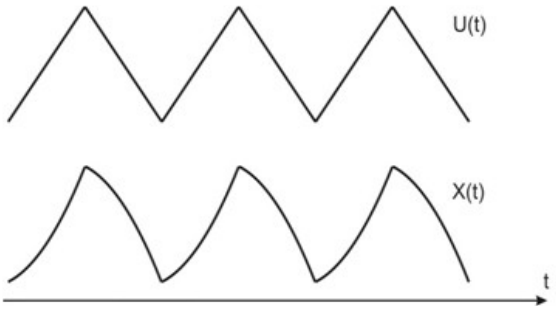


Fig. 5.7 a) Scanner motion along x direction with triangular voltage raster.

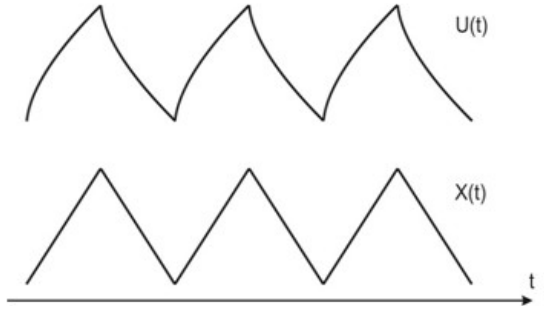


Fig. 5.7 b) Scanner motion with software non linearity correction.

- periodic motion of the scanner over time;
- Trajectory is monotonous between the extreme points

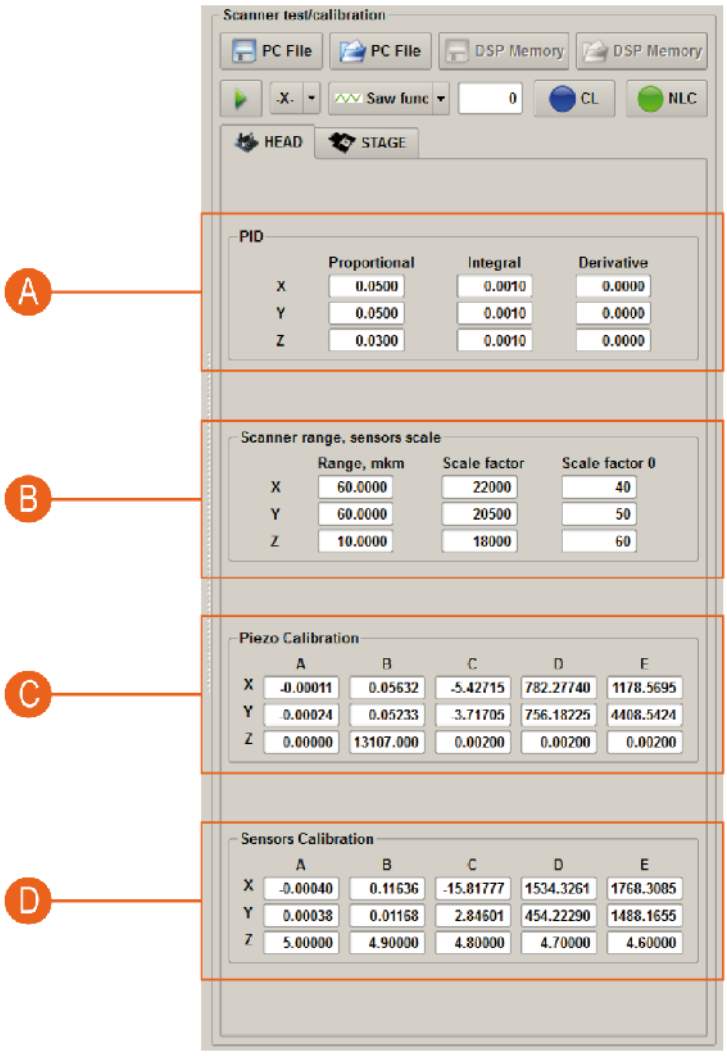
These conditions are always satisfied for fast scanning axis. If the size of the field on the slow axis is comparable with the full range of the scanner along this axis, the software nonlinear correction works satisfactorily for the slow direction. If the scan area is small, to eliminate distortions in the slow axis, scan area may need to be re-scanned (see explanations to Fig. 5.9 and Fig. 5.10).

Program scan correction allows to

reach the residual non linearity of less than 1%. Typically, for a fast scan direction residual non-linearity is about 0.3% for the slow - 0.5%.

5.2. Scanners calibration and non linearity correction in NSpec Software

To implement the nonlinear correction, go to the option Oscilloscope , clicking in the upper toolbar, the corresponding icon. In the right pane, find the section Scanner test /calibration (Fig. 5.12).



A	PID regulator for capacitance sensors
B	Scanner range.
C	Scanners software correction for open loop mode.
D	Scanners capacitance sensors non linearity correction table for close loop mode.

Fig. 5.12 Non linearity correction tables.

		CL	On/Off button for feedback sensors. When you turn feedback sensor button turns green.
		NCL	On/off button of the non linearity correction. When you turn on correction of non linearity, button turns green.
		PC File	Opening PC-File with calibration.
		PC File	Saving to PC-File with calibration.
		DSP Memory	Load calibrations form DSP memory of the controller
		DSP Memory	Save calibrations to DSP memory of the controller

From the above theory, non-linear conversion of the voltage U applied to piezostacks is required the appropriate direction of movement of X. In the system of EG-3000:

$$U(X)=A\times X^4+B\times X^3+C\times X^2+D\times X+E,$$

U – voltage in DACs counts 0...65535, X – displacement in μm, $0...X_{max}$ **(**range**),** this function is working at NLC is ON

, if NLC button is off, voltage is calculates as linear:

$$U(X)=65535\times\frac{X}{X_{max}}.$$

Therefore, to calculate the coefficients of the non linearity is necessary to conduct the following steps:

- switch off correction and feedback sensors

;
- establish a scanner range 65,535 x 65,535 μm;
- scan test pattern (Fig. 7.15) with the full amount of points (1000 x 1000) in the direction of the calibration, and the full range, direction and a starting point we choose the upper left, the direction of the fast scan X (measurements should occur on the growth of the voltage from minimum to maximum) ;
- produce a horizontal section of the image (Fig. 5.13).

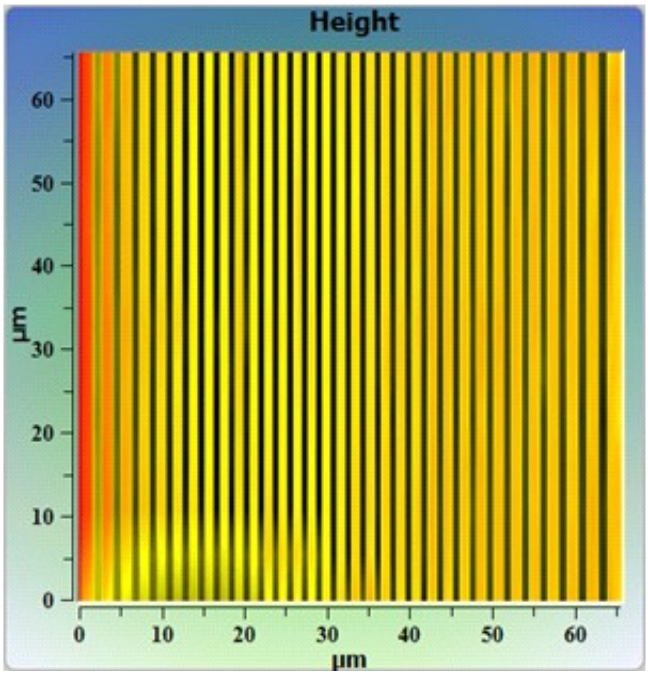
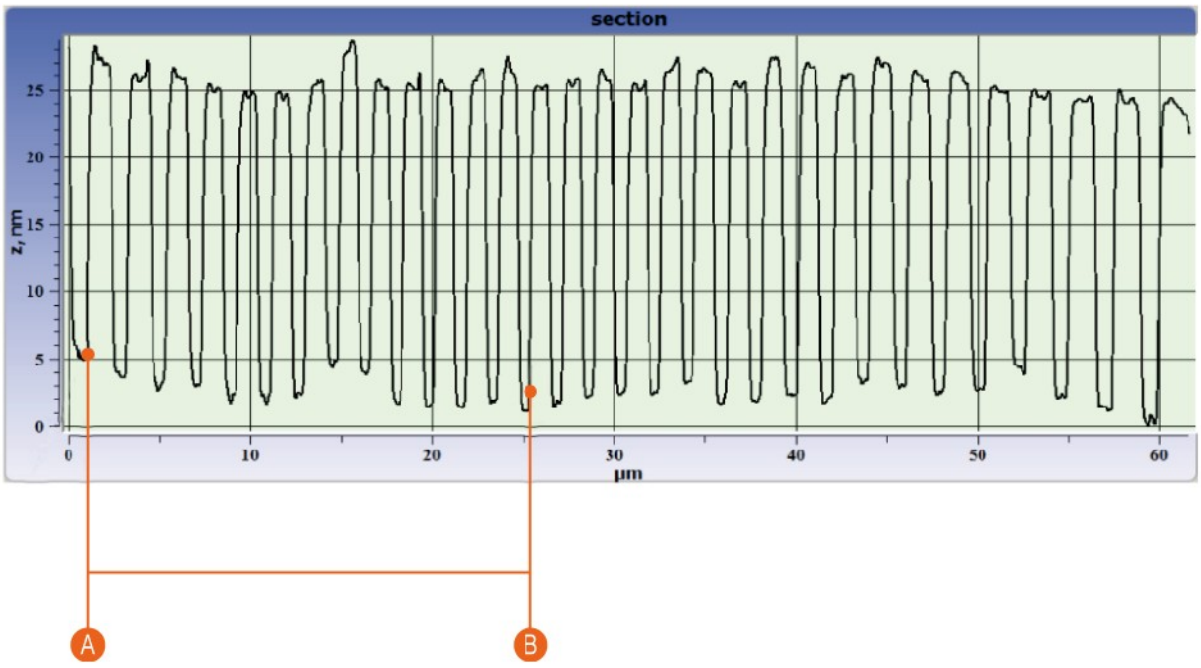


Fig. 5.13 Test picture.



A	Zero point X(0)=0 µm. U(0)=1000 x (measured X in µm).
B	Point N, X(n)=n x T (µm), T — period. U(n)=1000 x (measured X in µm).

Fig. 5.14 Horizontal section.

Fill in the table of values of voltages and displacements as follows: for the zero movement on the left, select the first point, which is uniquely characterized as the beginning of a new period, a shift which will then be formed will be automatically coun-

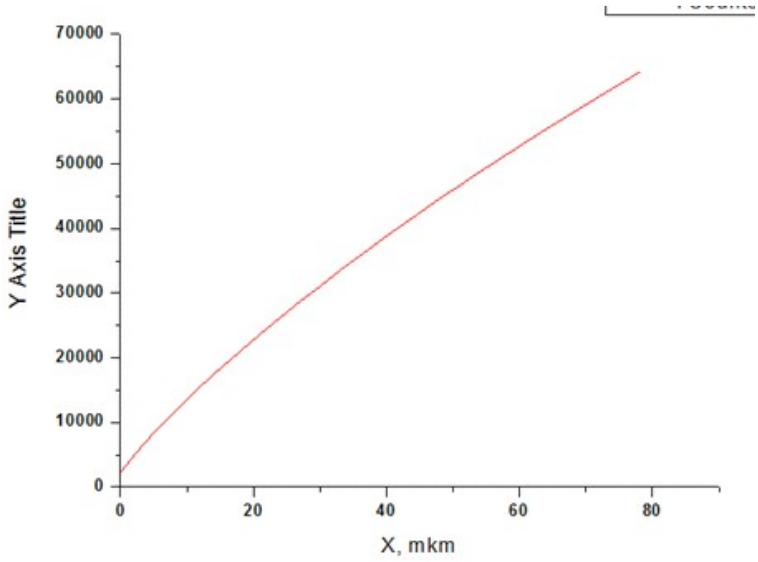
ted, i.e. X (0) = 0 μm, U (0) accurately measured value of the X-axis section in microns, multiplied by 1000. In the same way fill the remaining values: X (n) = n * T, where T-period in microns; U (n) = 1000 * (just measured the top n period in microns).

	Xmkm	YCounts
1	0	2296
2	3	6100
3	6	9512
4	9	12529
5	12	15547
6	15	18368
7	18	20992
8	21	23681
9	24	26174
10	27	28733
11	30	31029
12	33	33521
13	36	35752
14	39	38048
15	42	40278
16	45	42443
17	48	44608
18	51	46642
19	54	48741
20	57	50709
21	60	52742
22	63	54710
23	66	56613
24	69	58515
25	72	60418
26	75	62255
27	78	64157
28		

Then, using the supporting software perform fitting of tabular data by a polynomial of degree four:

$$U(X)=A\times X^4+B\times X^3+C\times X^2+D\times X+E,$$

Do the exact same procedure for the axis Y, with the only difference being that the direction and the starting point of scanning to be selected like the bottom left corner and the direction of a quick scan is Y-axis .



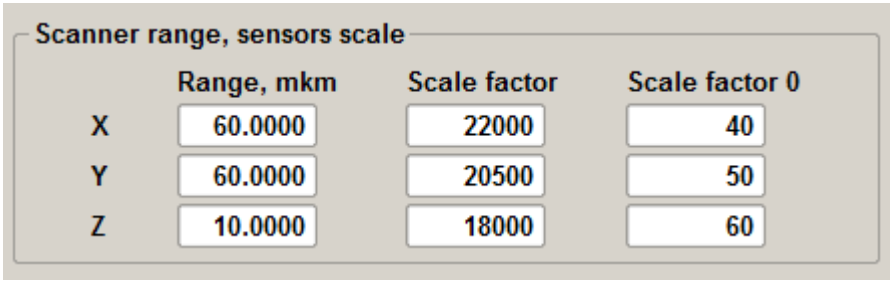
The data obtained should be recorded in the table and save the file.

Piezo Calibration

	A	B	C	D	E
X	-0.00011	0.05632	-5.42715	782.27740	1178.5695
Y	-0.00024	0.05233	-3.71705	756.18225	4408.5424
Z	0.00000	13107.000	0.00200	0.00200	0.00200

Then you must enable the correction of non linearity

, scan once more a test object, make sure the correct operation of the system and find the maximum range of scan and bring it to the table and the file:



5.3. Capacitance sensors correction

The procedure is very similar to the correction of non linearity of the piezo, with the only difference being that it is necessary to recalculate the capacitance value (instead of the voltage).

Procedure is following:

- Switch on capacitive sensors feedback and switch off the nonlinear correction

, all the processes now is taking place in the mode of feedback for capacitive sensors (Close loop) and NLC button now turns on and off the correction of sensors, rather than the scanner.
- $C(X)=A\times X^4+B\times X^3+C\times X^2+D\times X+E$, C – *sensor capacitance* 0...65535, X – displacement in µm, $0...X_{max}$ **(**range**),** function works at NLC

, is on, if NLC button is off : $C(X)=65535\times\frac{X}{X_{max}}$.
- Set scanner range to 65,535 µm x 65,535 µm
- Scan test pattern (Figure 7.17) for the full amount of points (1000) in the direction of the calibration and with full range, direction and a starting point we choose the upper left, the direction of X - (measurements should occur on the growth of the voltage from minimum to maximum).

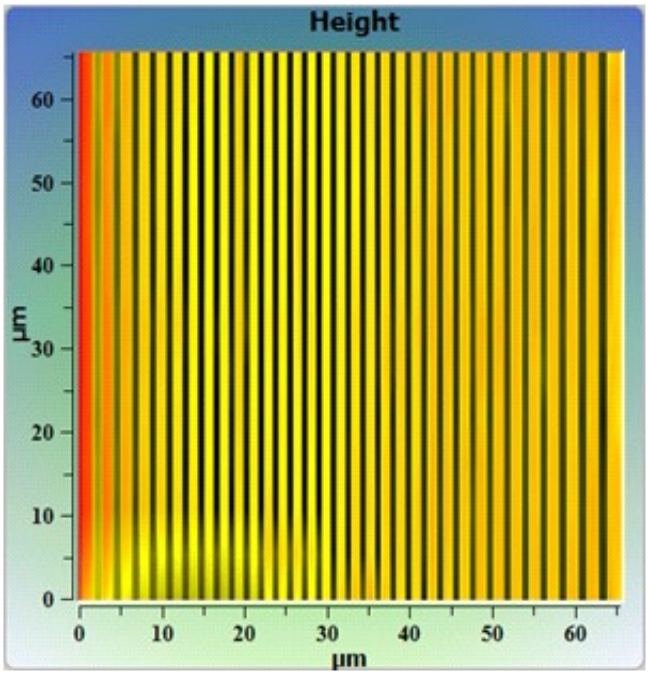
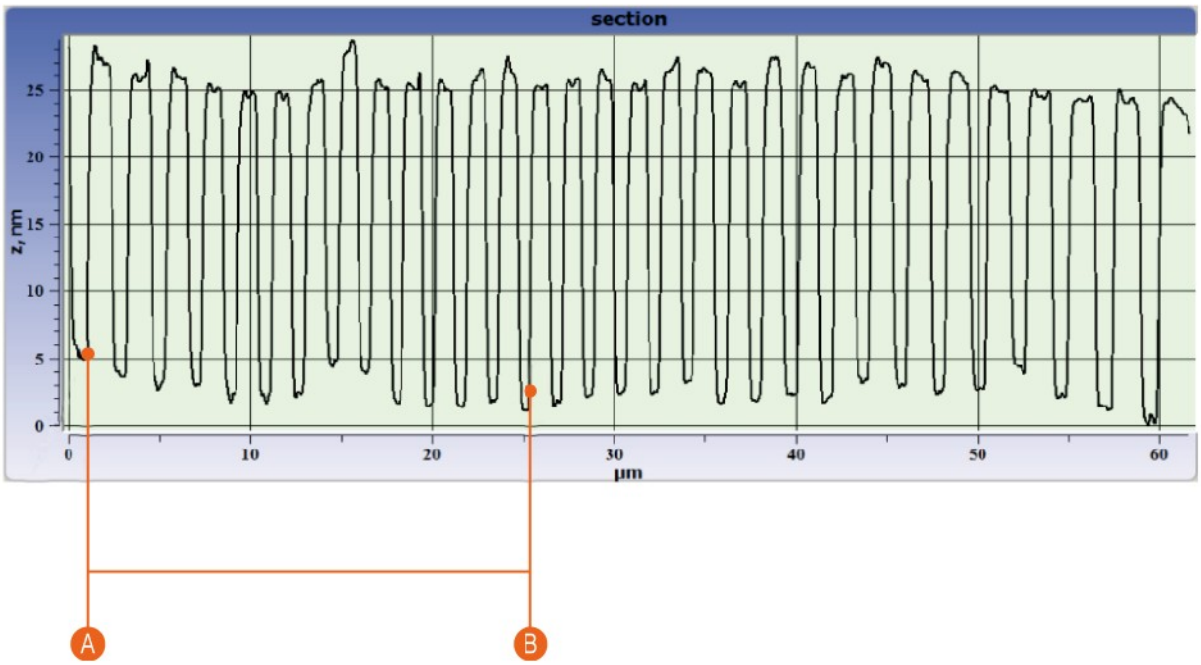


Fig. 7.17.17 Test pattern.

- Make a horizontal section (Fig. 7.18):



A	X(0)=0 µm. C(0)=1000 x (measured value X in µm).
B	X(n)=n x T (µm), T — period. C(n)=1000 x (measured value X in µm).

Fig. 7.18 Horizontal section.

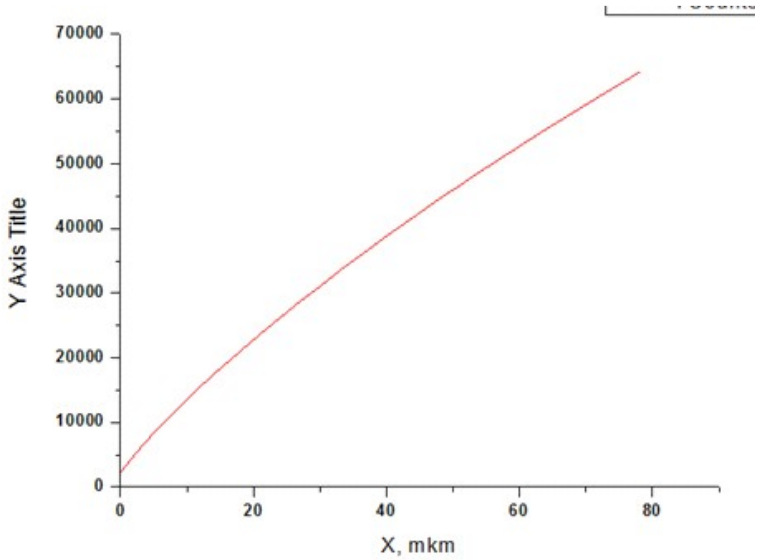
Fill the table of the capacity and displacement as follows: for the zero movement

on the left select the first point, which is uniquely characterized by a new period, a shift which will then be formed will be automatically taken into account,, t X (0) = 0 μm, C (0) = accurately measured value of the X-axis section in microns, multiplied by 1000. In the same way to fill the remaining values: X (n) = n * T, where T-time in microns, and C (n) = 1000 * (accurately measured the beginning of period n in microns).

Then, using the supporting software perform fitting of tabular data by a polynomial of degree four:

	Xmkm	YCounts
1	0	2296
2	3	6100
3	6	9512
4	9	12529
5	12	15547
6	15	18368
7	18	20992
8	21	23681
9	24	26174
10	27	28733
11	30	31029
12	33	33521
13	36	35752
14	39	38048
15	42	40278
16	45	42443
17	48	44608
18	51	46642
19	54	48741
20	57	50709
21	60	52742
22	63	54710
23	66	56613
24	69	58515
25	72	60418
26	75	62255
27	78	64157
28		

$$C(X)=A\times X^4+B\times X^3+C\times X^2+D\times X+E,$$



Do the exact same procedure for the axis Y, with the only difference being that the direction and the starting point of scanning to be selected like the bottom left corner and the direction of a quick scan is Y-axis .

The obtained data should be recorded in the table **Sensors Calibration** and save the file Y.

6. SPM Certus head application with external optical equipment.

6.1. Basic principles of optical equipment application

Scanning probe microscope is designed for use with optical equipment. The design of the SPM head Certus can combine it with both direct and inverted microscope, to sum up additional sources of light such as lasers, microscopes using regular light sources, etc.

One of the major limitations of scanning probe microscope is the difficulty in finding the site of interest on the surface of the research object, as well as the installation of the probe to a selected point on the surface. Circumvent this restriction allows the use of methods of optical microscopy and spectroscopy. Example of possible positions of the upright microscope lens is given in Figure 6.1.

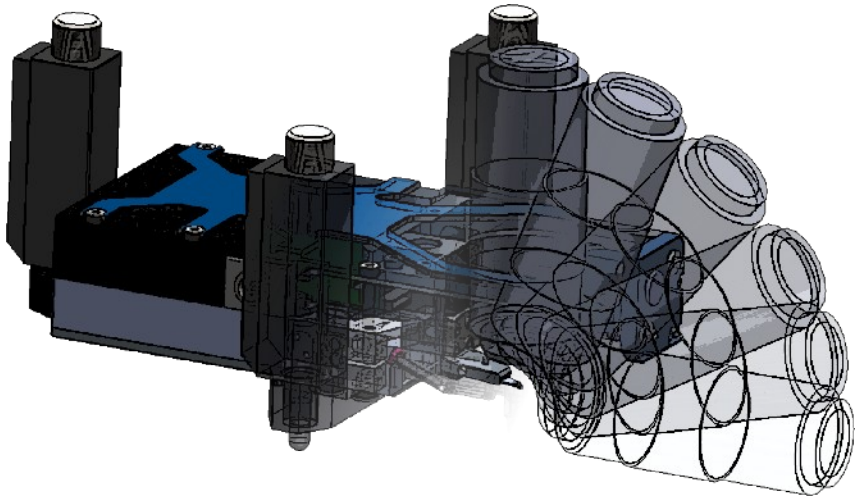


Fig. 6.1. External objective application.

Possible range of the micro objective position is 0-180 ° relatively to the axis passing through a probe tip. The maximum diameter of the lens used in the case of direct microscope - 40 mm, and in case of an inverted microscope the diameter of the lens used is limited only by lens design.

Working distance of the lens used (WD) is 12 mm for direct microscopy, and for the inverted microscope is limited only by the thickness of the used substrate.

6.2. Examples

The combination of the upright optical microscope allows to study both transparent and opaque objects. Example of such a combination is given in Fig. 6.2

Fig. 6.2. Combination with upright microscope.

In this case, you should align microscope field of view and tip position (Fig. 6.3). Furthermore, using optical microscopy techniques and developments for the sample to highlight areas on the surface of the object of research and scans.

The combination with an inverted optical microscope has meaning only in the study of the surface of transparent samples. An example of such a combination is given in Figure 6.4

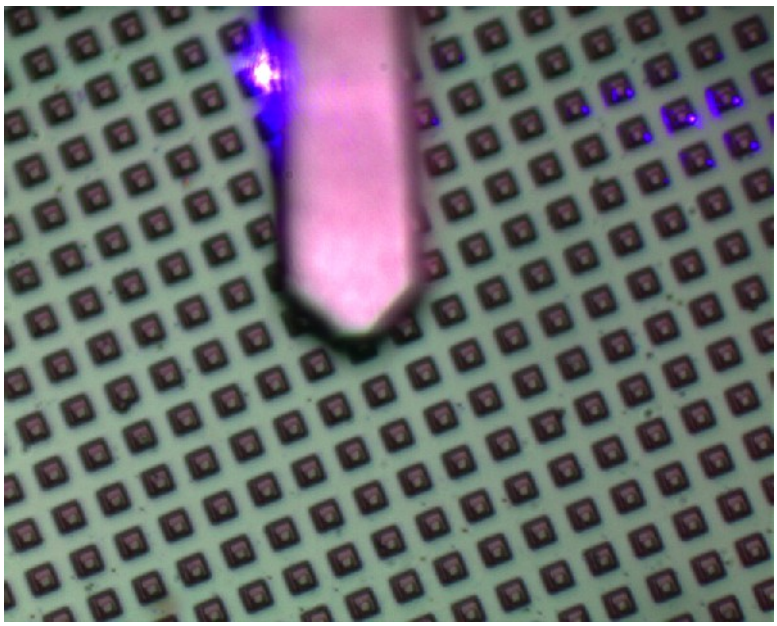


Fig. 6.3. Sample and cantilever tip image

Fig. 6.4. Combination with inverted optical microscope.

In this case, a basic algorithm for combining similar reconciliation with the upright optical microscope. However, please be aware that look to the bottom. And the optical image and the SPM image in the presence of similarities in the image will be mirrored each other. Example image of the probe and the object of study is given in Figure 6.5.

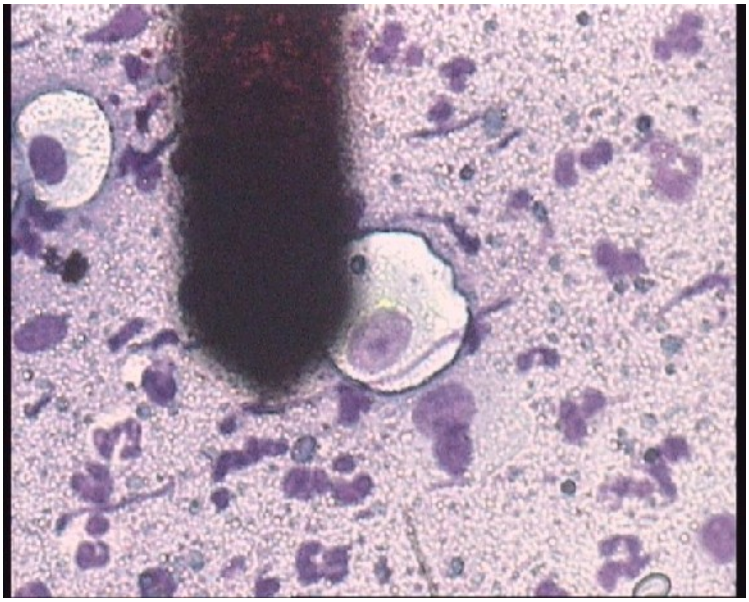


Fig. 6.5. Image of the sample and cantilever tip.